USAAML TECHNICAL REPORT 65-36

DESIGN CRITERIA, TECHNICAL CHARACTERISTICS, AND DESIGN CONCEPTS FOR AN AIR TRANSPORTABLE CONTAINER

C-66529

By

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John H. Watts
Robert M. Lucas

June 1965

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

CONTRACT DA 44-177-AMC-210(T)
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The cost effectiveness analysis of a modular air transportable container concept to be used for CONUS-to-user (Combat Zone) airline of communication (ALOC) as a means for improving combat logistic support by Army-type transport aircraft provides the basis for this investigation.

This Command concurs in the approach and analytical techniques used by the contractor in conducting this analysis. The study clearly indicates that effectiveness improvements accrued to Army aircraft in the intra-theater movement phases by virtue of the modular air transportable container are minor. Consequently, follow-up phases (design fabrication and test) as recommended by the contractor are not being scheduled.

Cost effectiveness gains indicated for the total ALOC appear to be of sufficient magnitude to warrant consideration. Accordingly, this report will be forwarded to the U. S. Army Logistics Management Center for consideration under their project, "Study of Unitization Systems, Policies and Techniques" (SUNSPOT).

Task 1M643324D59808
Contract DA 44-177-AMC-210(T)
USAAML Technical Report 65-36
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ABSTRACT

This report presents the results of a study to determine the feasibility of containerization for Army resupply items. The study has been limited to air transportation of supply classes I through IV shipped from a point of origin in the United States to an overseas forward area.

Container criteria for size, weight, cost, strength, effectiveness and general characteristics were developed. Then the design criteria were used as the basis for evaluating the suitability of various materials and conceptual container designs. An acceptable container design appears to be feasible.

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SUMMARY

This report analyzes containerization for air shipment of Army resupply items from CONUS to the point of use overseas. The transportation system for moving Army resupply includes commercial surface, MATS and Air Force theater airlift, plus Army aircraft and surface vehicles. Unitized pallet loads of standard size have been used as the basis for comparison to the proposed container system, and the container has been considered as a nonaccountable item to be used only once.

The study has been done in two phases. In Phase I, the container criteria for size, weight, cost, strength, effectiveness, and general characteristics were developed. In Phase II, the design criteria were used to evaluate the suitability of various materials and conceptual container designs aimed at fulfilling these criteria. Using the constraints specified in the statement of work and the criteria developed therefrom, a container which will meet all requirements appears to be feasible.

There is no significant operational effectiveness improvement for a container system in comparison to unitized pallet loads when considering such effectiveness measures as response time for support operations, aircraft restraint operations, or terminal operations. Effectiveness improvement will accrue principally to the Air Force through increased aircraft capacity if married container modules were transported through the air logistics system

As specified, the container has been considered for air transportation of all supply classes except bulk Class III and Class V (ammunition). Although rations and packaged POL are included in the resupply items to be air transported, the major usefulness of the proposed container system was considered for transporting other types of supplies.

The developed container criteria are as follows:

- Size = 44" x 54" x 70" high (approximately)
- Internal volume = 84 ft^3
- Allowable weight of container = 195 lbs
- Average weight of container and contents = 1600 lbs (approximately)
- Maximum weight of container and contents = 2000 lbs

justifiable cost has been estimated at $58.00. Of this amount, savings resulting from replacing level A packing and unitizing material amount to an estimated $24.00. The additional savings are a direct result of replacing the 463L master platform by multiple container units when transporting supplies through the ALOC.

The strength requirements imposed by the 9 g forward restraint dictate a container construction of such quality that it could be reused if recovery were practical and retrograde shipment were economical.

CONCLUSIONS

1. Using the constraints specified in the statement of work and the criteria developed therefrom, a container that will meet all requirements except the minimum justifiable cost appears to be feasible.

2. The preferred container design is estimated to weigh 161 pounds and cost $62.80. This weight is 34 pounds less than the estimated allowable weight, and the cost is $4.80 in excess of the minimum estimated justifiable cost.

3. Strength requirements dictate a container construction that is capable of reuse, even though this study has been based on a single trip.

4. The 9 g forward load factor is the controlling design requirement for strength. The container has been designed to yield, but not to rupture under this condition.

5. A container that does not replace the 463L master platform and net holds no specific advantages for air transportation over present unitizing methods such as the STRAC pack.

The following conclusions were drawn during the Phase I study of design criteria and technical characteristics.

6. The preferred container size is 44" x 54" x 70" high outside dimensions, having 4" base height, 3/4" wall thickness, an internal volume of approximately 84 ft^3, and an average loaded weight of approximately 1600 pounds.

7. The container should be modular to the 463L materials handling support system and should fit aircraft equipped with this system without the use of the MATS cargo platform.

8. Allowable container weight, based on level A packing and unitizing materials replaced by level C packing, ranges from 128 lbs to 338 lbs, depending on the quantity and type of level A packing materials replaced.

9. Container design weight, based on replacing an average pallet load consisting of 10% wooden boxes, 25% V2S carton material, and 65% V3C carton material is 195 lbs.

10. Estimated savings in packing material cost resulting from containerization range from \$18.00 to \$36.00, depending on the quantity and type of level A packing materials replaced. Based on replacing an average pallet load consisting of 10% wooden boxes, 25% V2S, and 65% V3C carton material, the savings in material is \$24.00.

11. Estimated savings in transportation, handling, and labor for moving the container through a typical ALOC from CONUS to overseas battalion range from \$34.00 to \$67.00, depending on the length of the ALOC.

12. Savings in cost and increased effectiveness will accrue to the Air Force as a result of introduction of the proposed container in the air logistics system.

13. Increased effectiveness in the form of "recovered" airlift capacity would accrue to the Army if, when the 463L system is introduced, the proposed container is transported instead of using the "pallet on pallet" system.

14. Containerization will reduce cargo damage, breakage, and pilferage to a limited extent.

15. It is uneconomical to return empty containers to the United States by air transport.

RECOMMENDATIONS

1. Detail design, procurement, and testing of a prototype container should proceed, with minimum production cost being an important objective.

2. Further consideration should be given to container reuse in evaluating potential cost savings.

INTRODUCTION

Technical advances have brought about radical changes in the concepts for warfare in recent years. In addition to the rapid advances in weapons, corresponding advances in transportation and communications have resulted in a high degree of mobility for fighting forces. This has complicated the logistics of supplying highly mobile field forces. The problem is complicated further by the complexity of equipment necessary for sustaining a fighting force. An ever increasing number of spare parts and supplies is required to keep the equipment in operation. Rapid response to logistic demands is assuming greater importance, thus making air transportation necessary in many cases. This is likely to become still more important as supply bases on foreign soil are phased out and greater reliance is placed on direct logistic support from the United States.

Much thought is being given to the possibilities of streamlining and standardizing the resupply function. The Army has adopted the 40" x 48" pallet as a standard for unitizing loads of resupply items. Plans such as supply segmentation are being considered for simplifying the huge resupply problem. Under ordinary conditions, supplies would be stockpiled at distribution points overseas, and they would be shipped to the user by the most appropriate transportation means. However, the need for a complete air line of communications (ALOC) extending from the United States directly to the user in the field is recognized for rapid response to logistic support.

THE DISTRIBUTION SYSTEM

Supplies that must be transported by air from a point of origin in the United States would be airlifted by the Air Force. Figure 1 illustrates the general flow of cargo originating at an Army depot or factory in the United States to the brigade level overseas. The first segment in the system would be by truck or rail to the most convenient point for air transportation. For this study, it is assumed that the quantity of resupply to be airlifted would justify MATS pick up at an inland airfield. The cargo would be transported overseas via MATS where it would be transferred to the Air Force theater airlift. The theater airlift would deliver it to the Army at an interface point. From here, it would be airlifted by Army aircraft to the point of use. Army airlift would be either fixed-wing or rotary-wing aircraft. Also, it is possible that some segment of the transportation cycle in the foreign theater would be accomplished by Army surface vehicles The exact routing would depend on specific conditions.

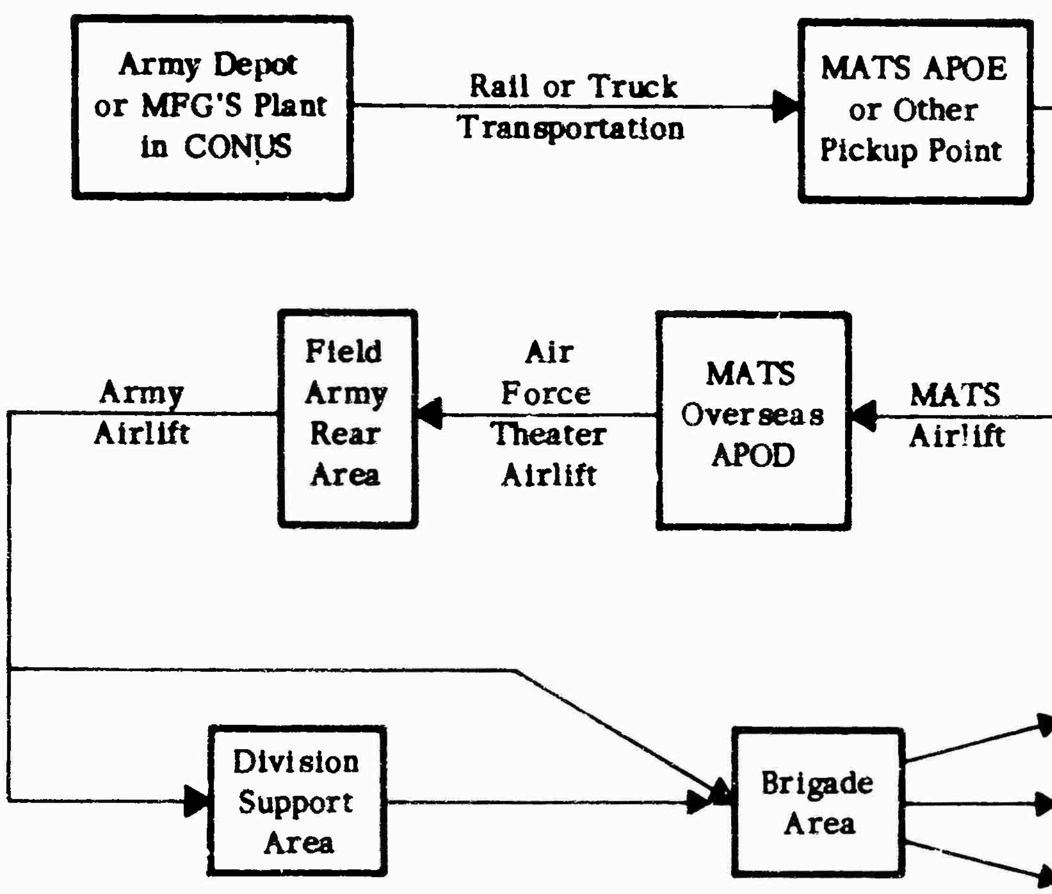

FIGURE 1 GENERAL FLOW DIAGRAM FOR CARGO FROM CONUS TO BRIGADE AREA

CONTAINER REQUIREMENTS

The container is considered as a possible replacement for the present method of unitizing and shipping resupply items on 40" x 48" pallets. General requirements, which are given in the USAAML work statement, are listed below. Other requirements for the container are developed throughout the report.

Compatibility With Military and Commercial Transportation System - The container size and carrying capacity should optimize the capacity of the Army CV-2, CV-7, and CH-47 aircraft. It should fit the Army 3/4-ton and 2-1/2-ton trucks efficiently. It will also be carried on the 25-ton flatbed trailer. The container should be compatible with the Air Force 463L materials handling support system. In addition, it should be compatible with commercial transportation vehicles and be capable of handling by standard forklift trucks plus field Army materials handling equipment.

Protection to Contents - The contents should be protected against weather and other environmental conditions equivalent to military level-A packing.

Material Transported - Supply Classes I, II, IV, and packaged III will be transported.

Design Strength - The container should withstand forces encountered in air and surface transport and the associated terminal handling.

Weight - Container weight should be the minimum consistent with strength requirements. Maximum tare weight is specified as the equivalent of conventional overseas packing and unitizing materials replaced by the container. The target gross weight for the container and contents is 2000 pounds.

Modular Design - Containers should be capable of being joined in multi-modules to facilitate handling and transportation through those segments of the distribution system equipped to handle the larger modules. Joining and separating containers should be fast and efficient, without special tools or procedures.

Method of Delivery - In addition to delivery by the conventional air or surface method, the container should be airdroppable when adequate cushioning material is attached. Also, it should be capable of being transported as a slung load from a helicopter.

Other Uses - Upon delivery of its contents, the basic module or married multiples should be suitable for other field Army uses.

FACTORS INFLUENCING BASIC DESIGN

The fundamental purpose for any logistics system is to provide the timely delivery of goods in usable condition at the lowest cost. The design of the proposed container must be aimed at achieving this goal. As described earlier in this report, the delivery of Army supplies by air to an overseas destination utilizes the Military Air Transport Service and Air Force Theater Airlift. These two air transport systems constitute the major portion of the distribution system in terms of miles. Hence, an improvement in the efficiency of these systems would result in substantial savings, due to the distance traveled.

These Air Force service organizations are being fitted with 463L materials handling support equipment. One of the features of the 463L system is the cargo platform which is used for unitizing loads up to 10,000 pounds per platform. The master platform is 88" x 108" and weighs approximately 300 pounds. A half-size platform is 54" x 88" and weighs approximately 175 pounds. At the present time, these platforms, plus associated netting, are used for unitizing nearly all general cargo transported in 463L equipped aircraft.

Substantial improvement, either in terms of dollar savings or increased aircraft carrying capacity, would be realized if the proposed container system were designed to fit the installed 463L equipment in aircraft without using the unitizing platform and net. Accordingly, we have considered only container sizes that are modular to the installed aircraft handling equipment. The influence of this approach is illustrated in this report by estimating the transportation cost of a container which does not fit the installed 463L roller and rail system.

The new Army CV-7 transport aircraft is to be equipped with the 463L roller and rail system for experimental use. If the Army decides to employ this materials handling system, or a comparable system, comparable savings would be realized by the proposed container.

Design Characteristics

The container is envisioned as being right rectangular with fastening devices at the corners for joining individual units together. Figure 2 illustrates the proposed concept. The container base would be designed with a groove extending

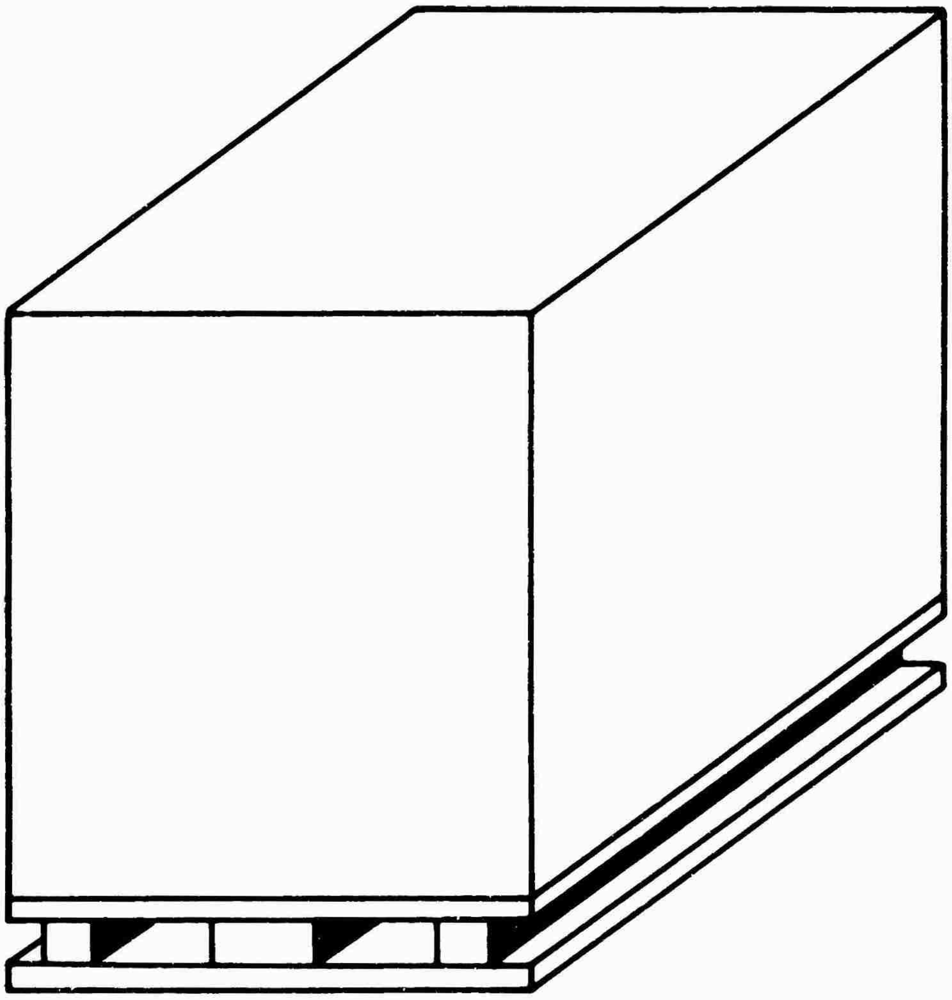

FIGURE 2 CONCEPT OF A MODULAR CONTAINER FOR ARMY SUPPLIES

around all four sides. This groove would fit the installed restraining rails of 463L aircraft. The bottom face of the container would be flat for rolling on conveyors. The base section of the container would incorporate four-way entries for forklifting.

SIZE AND CARRYING CAPACITY EVALUATION

The factors which affect container size and capacity are considered in this section. The limitations on size and capacity which are imposed on the container by the stated requirements are listed. Additional requirements, developed as a result of analyzing the interaction of possible container shapes and sizes with system characteristics, are discussed. A quantitative analysis of cargo density and size distribution is developed. The efficiency of containers as cargo carrying devices and their efficiency in various vehicles is analyzed. Three acceptable containers are chosen from the sizes evaluated.

LIMITATIONS ON SIZE AND CAPACITY

Restrictions placed on the size and physical configurations of containers by the separate transportation systems are summarized in Table 1. Commercial truck and railroad car effects are included because they make up a portion of the ALOC.

TABLE 1

INFLUENCE OF TRANSPORTATION SYSTEM ELEMENTS ON SIZE CHOICE

Transportation Element	Effect on Container Dimensions	Effect on Container Configuration
Army Surface Vehicles	Must fit in all truck cargo spaces (described below), must be of size to maximize cargo capacity, width-length must be less than 45-1/2 x 64", and height should be less than 54" (3/4-ton truck dimensions).	Limits maximum size.
Army Aircraft	Must fit all spaces (described below), must fit the 88" rail system in the CV-7. Must be of size to maximize cargo capacity. Single or stacked height should be less than 70".	Must have adequate tie-down attachments and allow space for tie-down, where required.

TABLE 1 (contd)

Transportation Element	Effect on Container Dimensions	Effect on Container Configuration
MATS	Should approach area of 88" x 108" when joined, must be less than 120" high, singly or stacked.	If designed to fit in the rail system, it must fit exactly the 108" rail width singly or joined. Bottom surface must be designed to roll on 463L conveyors.
Air Force Airlift Theater	Same as MATS	Same as MATS
Commercial Surface		
Trucks	Should be less than 90" wide x 8' high when joined.	
Rail Cars	Should be less than 110" wide x 126" high when joined or stacked.	
Flatbeds	No unique requirements	

The six U.S. Army vehicles in which the Air Transportable Container (ATC) is intended to be carried have the following important characteristics as shown in Table 2. The aircraft capacities are chosen to correspond to the speed, altitude, and distance assumed for each plane's mission in the air resupply system. The mission characteristics will, of course, vary about the expected mission resulting in higher or lower cargo capacity. Use of the expected or average aircraft capacity does not affect the measures for performance of a particular container substantially. Truck heights represent available space in trucks with hoops and canvas tops installed, although these heights may be excluded.

TABLE 2

CAPACITIES AND DIMENSIONS OF ARMY TRANSPORT VEHICLES

Vehicle	Cargo Capacity (pounds)	Cargo Compartment Dimensions (inches)		
		Width	Length	Height
CV-2 - Caribou	7,000*	73.5	345	75
CV-7 - Buffalo	8,500*	92	377	78
CH-47 - Chinook	8,000*	90	366	78
M-37 - 3/4-ton Truck	2,000	45.5	63	54**
M-36 - 2.5-ton Truck	5,000	88	210	64**
M-172A1 - 25-ton Flatbed Trailer	50,000	115	192	--

* Estimated from Army Aircraft Characteristics, Office of Director of Army Aviation, Department of the Army, 30 November 1960. All other information in table supplied by USAAML.

** Dimensions under hoops.

Cargo of Classes I, II, IV, and III (packaged) are intended to be carried in the ATC. It is expected that by the time an ATC system is adopted and implemented, considerable change will have taken place in the design and, hence, in the configuration of much of the cargo intended for air resupply.

DEVELOPED REQUIREMENTS AS RELATED TO CONTAINER SIZE AND CAPACITY

Restraints are placed on the air transportable container system by the physical characteristics of the logistics system through which the container moves, the practical considerations of engineering design, the manufacturing costs, and the handling procedures. The following developed requirements result from an analysis of these restraints.

The Container Should be Right Rectangular, With Rigid Walls - This precludes the possibility of an odd-shaped, for instance hexagonal, container. Such an odd shape might have particular advantages in one situation or in one vehicle, but for a series of vehicles the only shape with sufficient loading flexibility is a right rectangular one. The requirement that the container have rigid walls obviates the possibility of expandable or flexible walls, inflatable, expandable, or other non-fixed configuration.

The Container Should be Handled in the Up Direction Only - This requirement is brought about by the fact that many items are packaged with the intention that they not absorb the same shocks or vibrations from the top or sides. Furthermore, handling in more than one direction would unduly complicate fastening modules together and fitting the 463L aircraft rails. This requirement eliminates an additional degree of freedom, however.

A Maximum Total Weight Should be Specified for the Container Plus the Cargo Contained - This requirement arises from the fact that the 3/4-ton truck has a specified maximum load of 2,000 pounds.

The Choice Should be Limited to One Container Size Only - Although a greater degree of flexibility would result from two or more size containers, the complications introduced throughout the logistic system outweigh this advantage.

The Container Preferably Should be Filled in the United States and not Opened Until Reaching the Final Destination - This removes the possibility of adjusting the weight of a particular container to meet the load capacity of a particular aircraft in a given situation.

Loaded Containers Should be Stackable for Storage - Containers of such height which would permit stacking in aircraft should have the additional capability of being fastened together when stacked.

The Container Should be Modular to the 463L System - A container, or group of containers when joined together, should fit the 88" rails of the CV-7 aircraft and the 108" rails of large Air Force transport aircraft.

CARGO DENSITY AND SIZE DISTRIBUTION

In order to choose a container size that has the requisite performance, it is necessary to establish estimates of two important cargo characteristics: the distribution of densities and the distribution of the maximum dimension for individual supply items.

Density Distribution

The nature of cargo density to be carried in a supply system affects almost every feature of the system, and consequently is a basic consideration in the design of container size. Cargo density directly affects the expected weight of a particular container, the container's utilization of space and weight capacity in a vehicle, the utilization of container internal volume, and the weight and volumetric efficiency of a container with a specified maximum weight.

Although it is impossible to precisely define the nature of the distribution of density of Army cargo that would be carried in a future air resupply system, it is necessary to construct an estimate of what this distribution is likely to be. Compilations of mean or average densities for the supply classes of interest have been made for recent studies of Army logistics. Table 3 includes such a compilation, and for comparisons the results of a study of actual unitized loads of Army overseas cargo.

TABLE 3

AVERAGE DENSITY AND PERCENT OF TOTAL CONSUMPTION FOR SUPPLY CLASSIFICATIONS

	#1 Average Density* lbs/ft^3	#2 Average Density** lbs/ft^3	#3 % of Total*** Consumption
Class I	23.8	37.12	36.1
Classes II & IV			
Chemical	13.2	14.4	.4
Engineers	31.8	25.5	3.7
Medical	20.0	17.1	.6
Ordnance	27.8	36.4	9.3
Quartermaster	27.4	17.8	7.5
Signal Corps	13.2	33.2	4.7
Transportation	--	42.8	.1
Class III (packaged)	33.3	--	37.7
			100.1

* Supply Segmentation and Unitization for Combat Support, QM Board Project No. 23, Quartermaster Board, U.S. Army, June 1961, p. 69.

** "Consolidated Recapitulation of 16 Gamb-Odex Army Ocean Manifests..." Based on unitized loads shipped from New York and Hampton Roads, 1952-1954. Unpublished working paper, USACDCTA, Fort Eustis, Virginia.

*** Based on FM 101-10, Part I, Staff Officers' Field Manual, Department of the Army, October 1961, p. 326.

These figures are somewhat inappropriate as a representation of the density of future air resupply cargo for the following reasons:

> They represent <u>mean</u> densities. In reality, densities in each cargo class vary widely and have a different distribution for each class.
>
> They represent World War II and Korean War experience--many of the supply items will have changed in weight and cube by the time they are incorporated into an air resupply system. They represent all supply items--initial and resupply, air transportable and non-air transportable, and in Column #1, unitizable and nonunitizable.

With these inadequacies in mind, however, a plot of cumulative proportion of cargo versus density can be constructed for comparison purposes. Using the densities in the first column and the usage percentages in the third column, the cumulative mean densities are plotted in Figure 3. In like manner, the observed densities of overseas unitized loads in Column 2 are combined with the usage percentages and presented in Figure 3.

Figure 4 is a cumulative plot of densities in Classes I, II, III (packaged), and IV, based on data more closely related to future unitized air resupply of combat divisions. The data sources were:

a. 58 unitizable items packaged for air resupply in the Korean conflict.[1]

b. 41 unitized loads of subsistence, clothing, and repair parts shipped from the New Cumberland, Pennsylvania depot, (1960).[2]

c. 29 selected supply items' densities when unitized on 40" x 48' pallets.[3]

Figure 4, although not weighted by theoretical consumption rates, is a useful reference for density range and distribution since the items from a. and b. were compilations of actual Army air or surface unitized supply, and since the data refers to discrete supply items, not mean densities for cargo classes.

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1 <u>Export Packaging Study for Aerial Delivery Planning</u>, September 1954, 7-87-03-004 Aerial Delivery Equipment.

2 Unpublished working paper dated 20 July 1960, Quartermaster Food and Container Institute for the Armed Forces, U.S. Army.

3 Based on several unpublished, undated working papers prepared by the Food and Container Institute, U.S. Army Natick Laboratories.

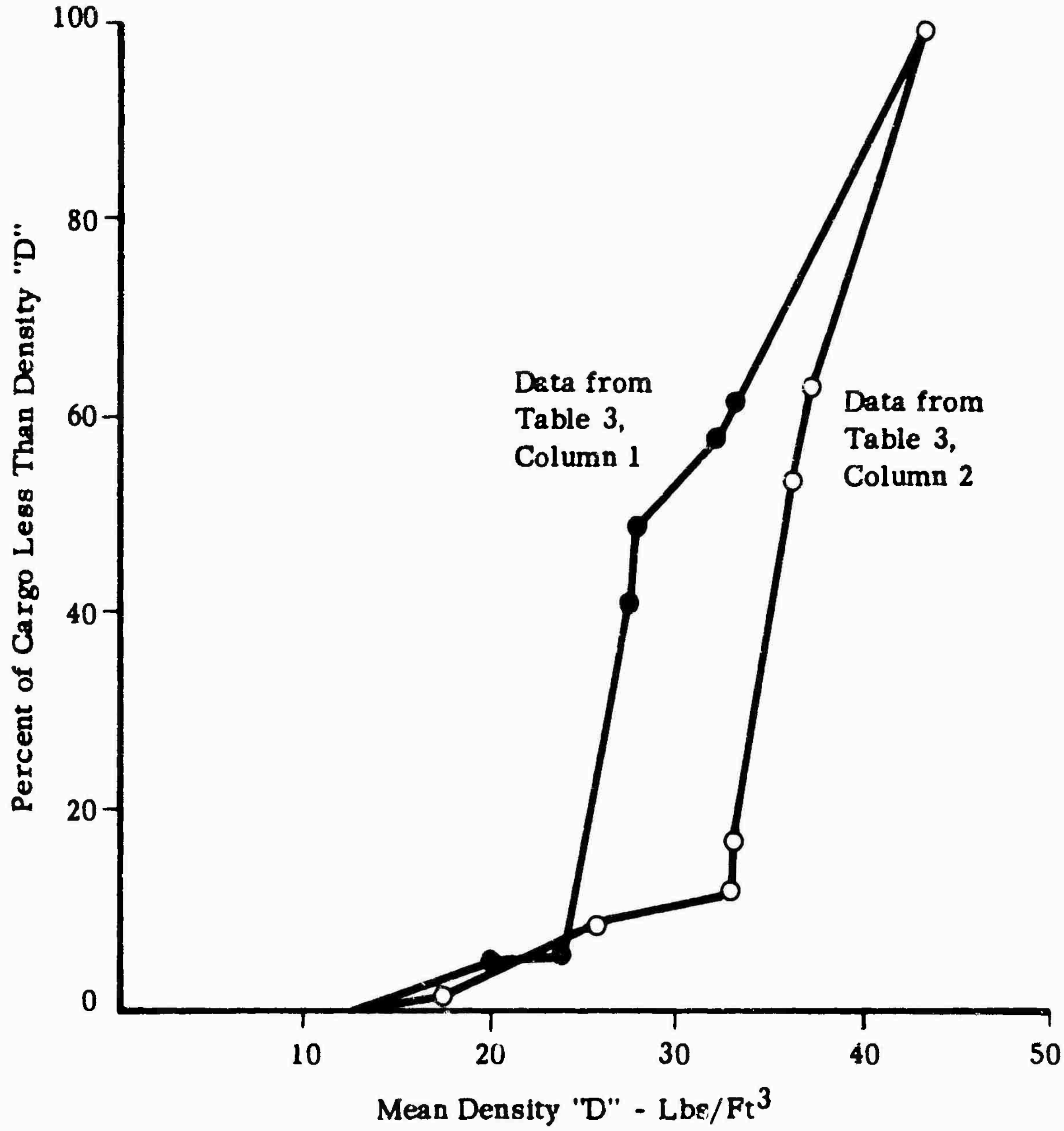

FIGURE 3 DISTRIBUTION OF AVERAGE DENSITIES FROM TWO DATA SOURCES FOR CLASSES I, II, IV, AND III (PACKAGED) ARMY CARGO

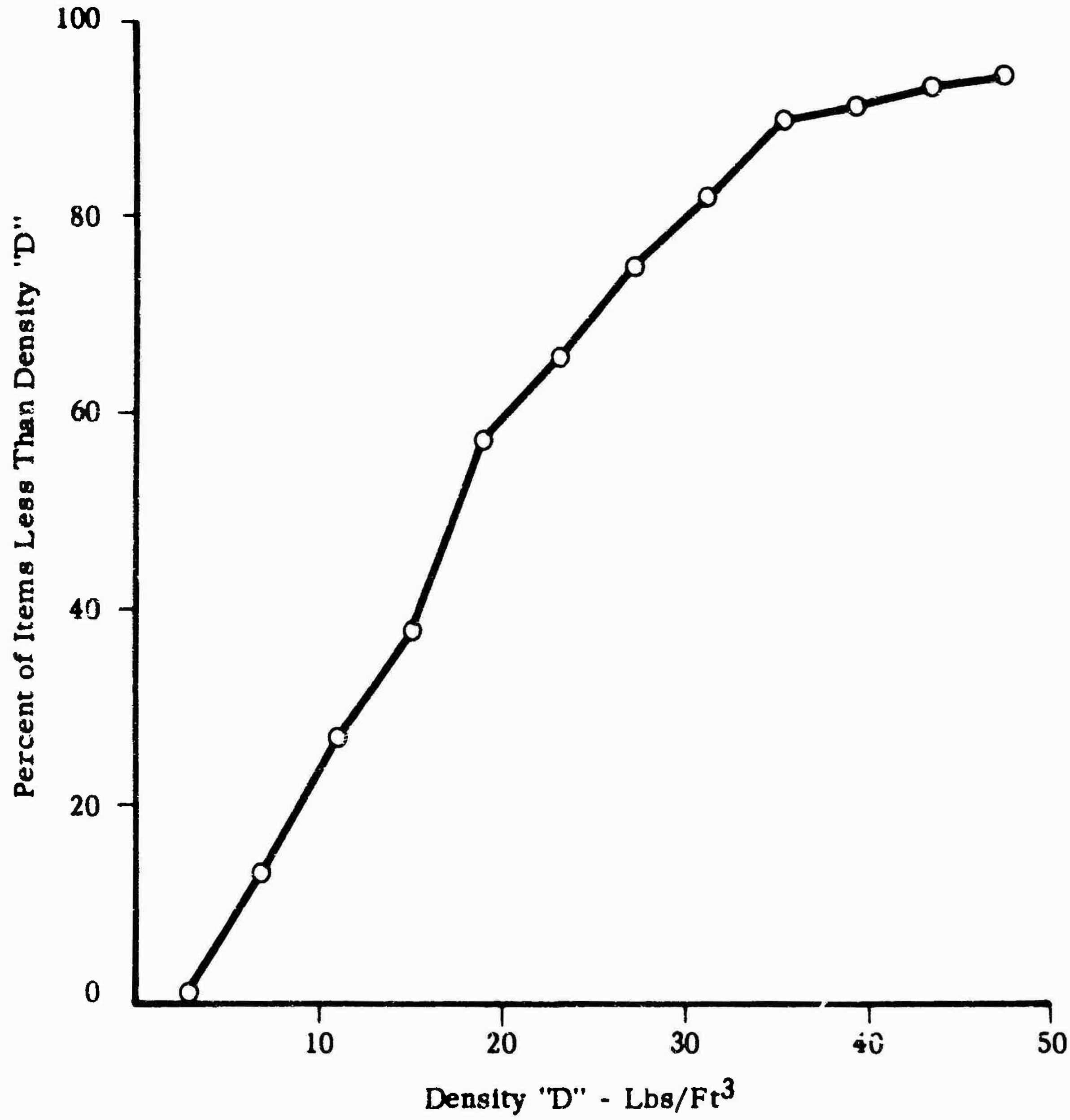

FIGURE 4 DENSITY DISTRIBUTION OF A SAMPLE OF UNITIZED ARMY SUPPLY ITEMS

The above air resupply cargo density distributions compare rather closely with commercial air cargo density. In a report[1] prepared for The Boeing Aircraft Company, a detailed analysis was made of a wide range of current and probable near-future air cargo freight classes and items, their densities, and their proportion of the total air freight tonnage. The resulting air cargo density distribution is redrawn on Figure 5. The average density for this distribution was 20.2 lbs/ft^3.

An assumed density distribution for future Army resupply based on the above information is shown in Figure 6.

This distribution has the following characteristics:

A range of density of 5 lbs per cu ft to 40 lbs per cu ft. These maximum and minimum figures are not meant to exclude the possibility of any heavier or lighter cargo, but to reflect the fact that, based on current and past densities of unitizable cargo, the preponderance of cargo is expected to fall within this range.

A straight-line distribution of densities over the range. This estimate results from an unbiased, or rectangular, frequency function of cargo density. Although such a flat frequency function may be defended as a reasonable expression of a variable whose detailed nature is not known, as is the case with future cargo density, it is interesting to note that Figure 6 agrees rather closely with the unweighted densities of Army cargo in Figure 4.

A mean density of 22.5 lbs per cu ft. This is about 15% lighter than the weighted average figure of 26.4 lbs per cu ft, resulting from weighting the current densities in column 1 of Table 3 with the consumption rates in column 3. This agrees well with the observed trend toward smaller but even lighter equipment, rations, and other cargo for air resupply.

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1 The Density Fantasy - Air Cargo Density Trends, Hackney Airlift Associates Incorporated, Sierra Madre, California, 1961.

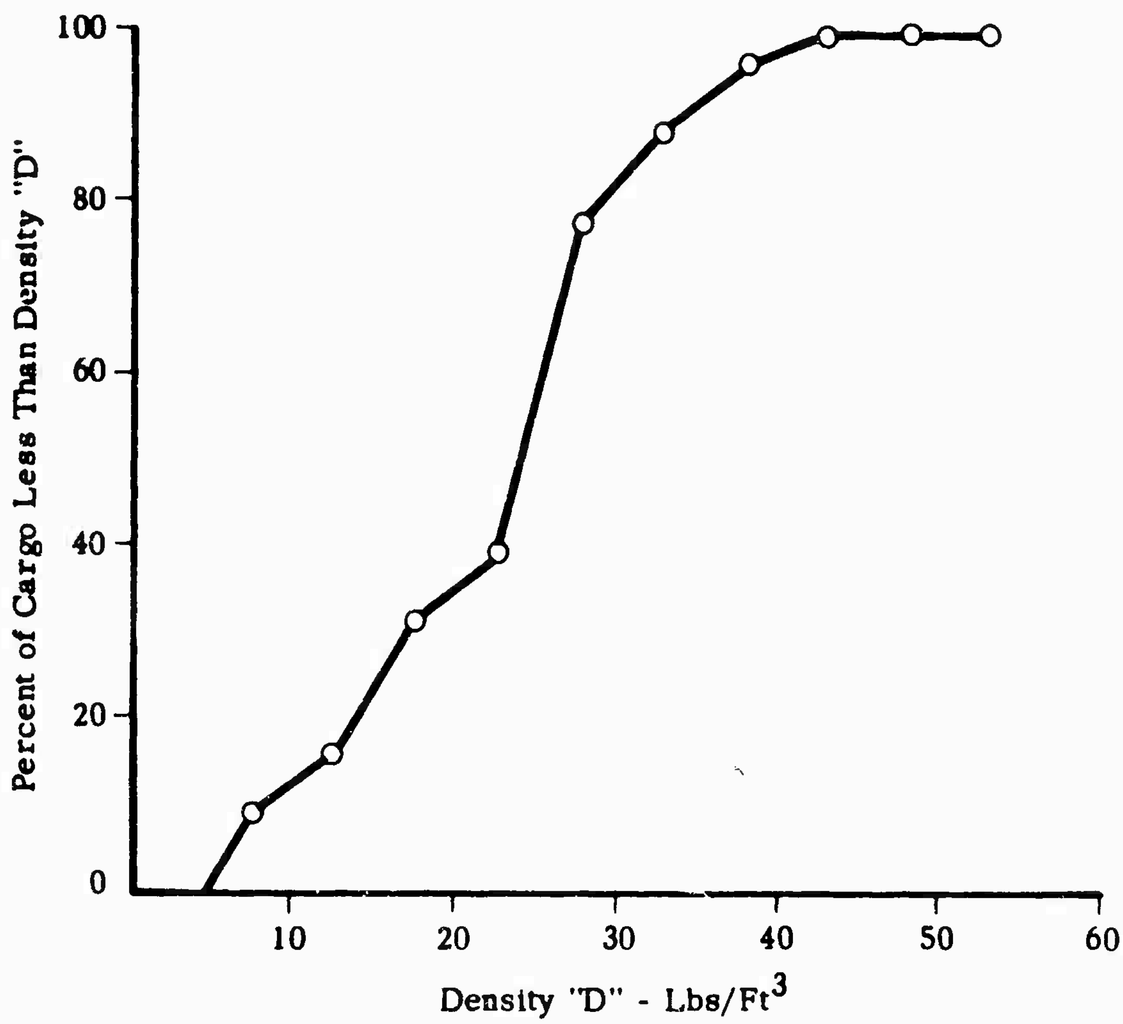

FIGURE 5 DENSITY DISTRIBUTION OF COMMERCIAL AIR CARGO

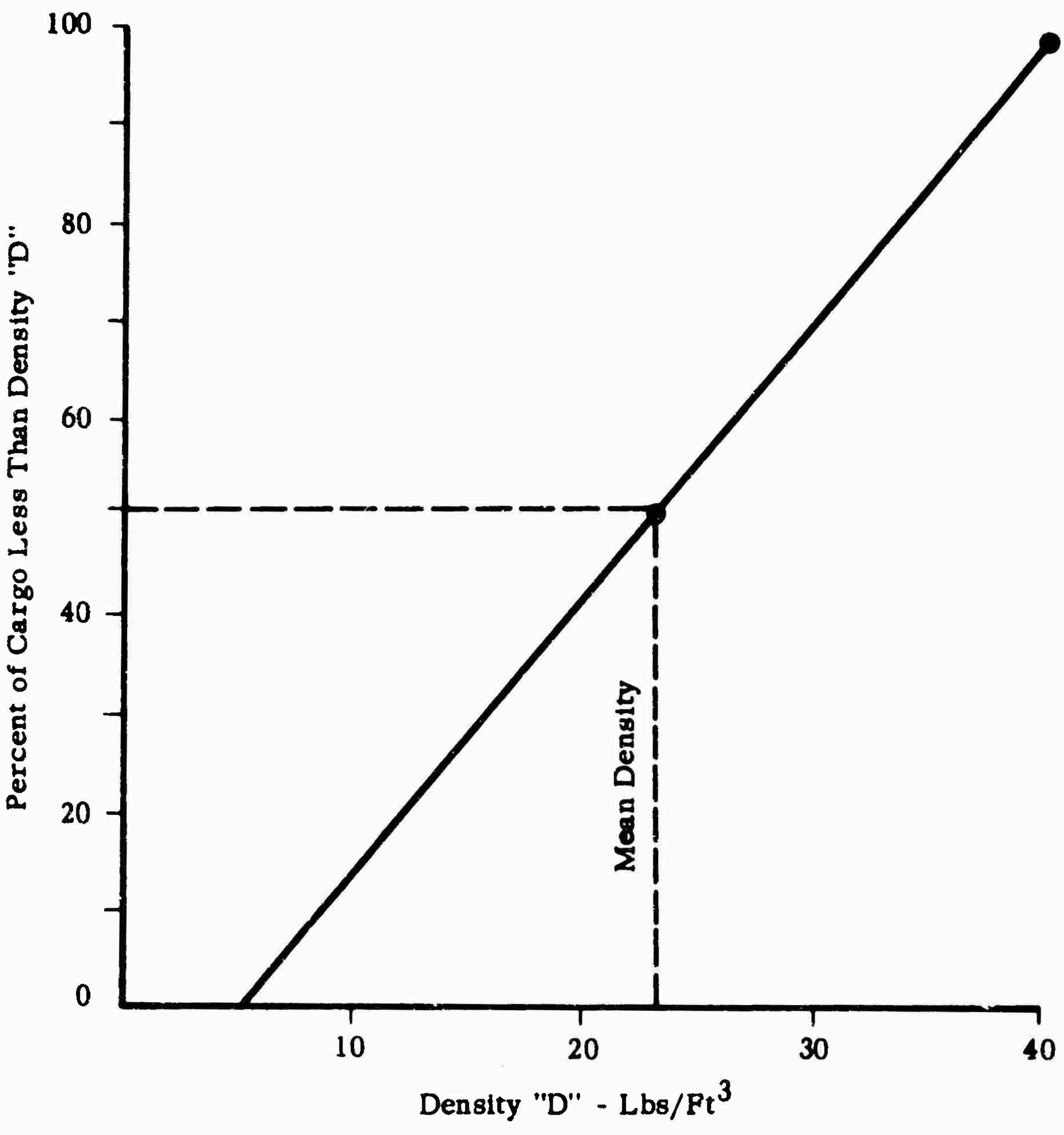

FIGURE 6 ASSUMED DENSITY DISTRIBUTION FOR ARMY RESUPPLY CARGO TO BE AIRLIFTED

Maximum Dimension Distribution

In the choice of an Army air cargo container size, it is desirable to select a size that would physically contain as great a proportion of cargo items as possible. Precise description of the distribution of dimensions in air resupply cargo packages is not feasible since the future mix of air-carried items is indefinite. An indication of the probable cargo length distribution is available, however, from records of Army resupply items airdelivered during the recent Korean conflict.

Akrep, in a recent report[1], analyzed available length data for unit packs of air-delivered cargo in the Korean conflict. Figure 7 summarizes the results of the analysis. From the data available, it appears that a container having a maximum internal dimension of 50" will contain the majority of Army air resupply items.

EVALUATION OF CONTAINER SIZES

In order to select an optimum container size or set of preferred sizes, it is necessary to establish criteria for evaluating candidate sizes, to develop a methodology for applying the criteria, and to arrive at the set of possible sizes that are consistent with the criteria.

Evaluation Criteria

A cargo container may be evaluated from two viewpoints: its performance or efficiency as a device for unitizing cargo, and its performance when used as a cargo containing element within the specific transport vehicles in a transportation system.

Measures of Efficiency as an Independent Unit

A number of approaches exist for evaluating the relative worth of a particular container as a cargo-carrying device. Some of these evaluation methods are more relevant than others, and most are not combinational; that is, the measures of evaluation cannot be added meaningfully. The most appropriate measures for the performance of an air transportable container considered independently from transport vehicles are as follows:

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1 A Survey of Quartermaster Corps Air Cargo Packaging Problems . . . . , QMFCIAF Report No. 2460, July 1960, p. 29.

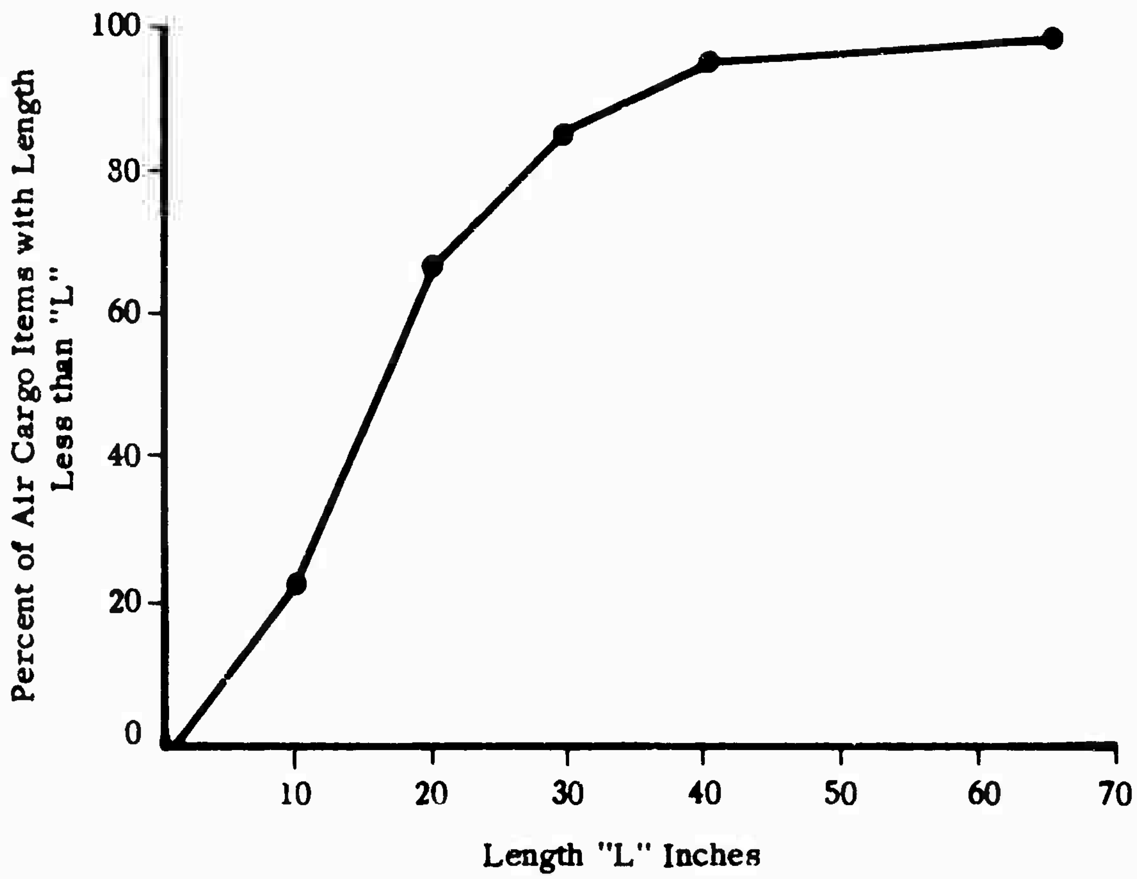

FIGURE 7 SUMMARY OF LENGTH DISTRIBUTION OF ARMY AIR CARGO IN UNIT PACKS DURING THE KOREAN CONFLICT

Volumetric Efficiency: This is a measure of the extent that a container system "gets in the way" of the transporting of the cargo itself. The container's external volume must be fitted into the larger "container"-- the truck, plane, or other cargo space. The container, however, has only its internal volume available for the actual cargo. Consequently, "Volumetric Efficiency" is defined as the ratio of a container's internal to its external volume.

Weight Efficiency: In similar manner, the weight of the container reduces the efficiency of the carrying vehicle. Unlike volumetric efficiency, however, the weight efficiency of the container is not a fixed figure. When the container is loaded to its specified maximum weight, the ratio of cargo (net) to cargo-plus-container (gross) weights is fixed. Otherwise, when carrying cargo of lower densities with which it is impossible to reach the maximum weight, the net/gross ratio will vary as the density varies. Consequently, the "Weight Efficiency" is defined as the expected cargo net weight divided by that net plus the container weight.

Internal Stowage Utilization Factor: When loose cargo is loaded into any space, not all of the available space can be utilized because the cargo packages do not fit the space exactly. Therefore, unused space may be expected in containers employed in air resupply unless all items are required to be packed in boxes whose sizes are modular to the internal dimensions of container.[1] If this requirement can be met, the "stowage factor" or ratio of volume utilization will be close to 1.0.

It may be expected, however, that this condition will not be consistently met for several reasons: (1) the large number of possible air resupply items would make such size control difficult; (2) the wide diversity in sizes of unpackaged items would cause space wastage if required to be packed in one of a small set of standard boxes; and (3) the items may be carried by cargo systems other than containers. Consequently, it should be anticipated that a certain proportion of the internal cubic

---

1 Such as the "General Purpose Containers" proposed in the report Supply Segmentation and Unitization, QMB Project No. 23, June 1961, Quartermaster Board, U.S. Army, Fort Lee, Virginia, p. 72. This modular subsize concept is also similar to the CONEX insert container.

capacity of the container will not be occupied with cargo because of the impossibility of perfect fitting.

Internal stowage factors experienced in modern cargo systems may vary between 0.50 for large items in ship's holds to as high as 0.85 or 0.90 with small rectangular boxes packed in large transporters or containers.

It is immediately apparent that stowage factor is a function of the container internal dimensions and dimensional ratios, plus cargo package dimensions and dimensional ratios. For a given population of packaged items, the expected internal stowage factor in a container will vary between containers of different dimensions. In general, as the internal volume decreases, the stowage factor decreases. It is also interesting to note that a package or a container with an exactly square base is not desirable, since the possibility of improving packing efficiency by changing orientation is reduced.

In a recent paper,[1] results of a detailed computer calculation of stowage factors were reported for a wide variety of package sizes stowed in containers of different internal volume. Stowage factors fluctuated widely for each package in varying container sizes, or for each container filled with varying package sizes. It is possible, however, to extract representative levels and trend of stowage factor versus internal volume for the package size range of interest (approximately .05 ft^3 to 6 ft^3) from the fluctuations caused by complex interactions of specific dimensional ratios. The lower curve in Figure 8 shows stowage factor extracted from the results in the report.

Improvements in stowage factor in an Army air cargo container over those calculated in the report will result from (1) mixing of different package sizes in modularized loads, or (2) adopting a limited amount of standardized package sizes designed for container fit, and (3) more ingenious packing than the simple choice routine that was used in the computer program. Because of these three factors, stowage loss (1.0 minus stowage factor) in an Army container is assumed to be only one-half as great as that calculated for the cargo treated in the report.

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1 An Engineering Analysis of Cargo Handling--VI Containerization, July 1957, by Joseph D. Carrabino, Department of Engineering, University of California, Los Angeles, sponsored by Office of Naval Research under Contract No. Nonr 233(07).

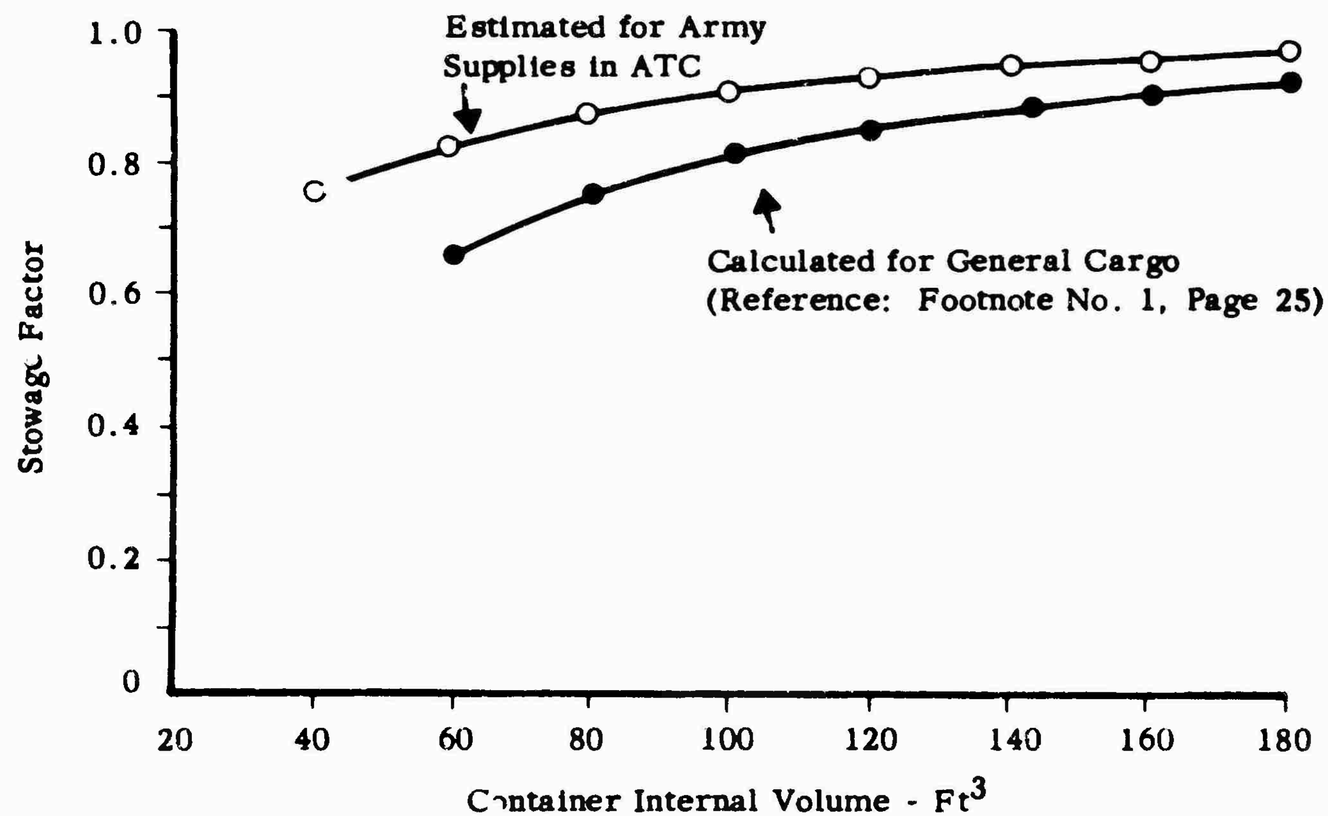

FIGURE 8 INTERNAL STOWAGE FACTOR FOR GENERAL CARGO AND ARMY RESUPPLY

If the stowage factor is adjusted upward by this consistent proportion, stowage factor as a function of container volume may be considered to behave as shown by the upper curve in Figure 8.

Measures of Cargo Carrying Efficiency in Vehicles

Besides the above considerations concerning the influence of a container's size on its performance as a cargo carrying device, it is necessary to examine the effect of container size on the cargo carrying performance of the aircraft and vehicles in which the container moves. Two requirements are readily apparent: (1) the weight carrying capacity of the vehicle should be optimized and (2) the vehicle cube utilization should be maximized.

Cube-Out Loss

In order to express the loss of vehicle capacity caused when the vehicle is filled with containers but does not contain its maximum capacity, the concept of cube-out loss is introduced. For each vehicle, the maximum number of a particular container that can be loaded within it is calculated. If, when this maximum number of containers is filled with cargo of the minimum density, the total weight is less than the vehicle capacity, a cube-out loss is seen to occur.

The critical cargo density is the density at which the maximum number of containers exactly equals the aircraft weight capacity when filled with cargo of that density. Below this critical density, cube-out loss occurs; above it, no cube-out loss is sustained.

Because the density assumption is based on a distribution of densities versus their frequency of occurrence, the probability of a cube-out loss can be calculated for each container in each vehicle. Similarly, the expected number of pounds of cube-out loss for the container-vehicle combination under study can be calculated. Figure 9 shows a plot of the density distribution, with the density at which cube-out occurs for a particular container and a particular vehicle plotted on the line and the method of calculating this density shown above the figure.

Step-Function Loss

A second class of cargo capacity loss occurs as a result of imperfect matching of total container load with vehicle weight capacity. For example, if containers weighing 2000 lbs are to be carried in an aircraft with cargo capacity of 7500 lbs, only three containers may be loaded aboard, since four would exceed the weight

CALCULATION

For vehicle with capacity = 7500 lbs

Container with effective internal volume = 38 ft^3 and tare weight = 150 lbs

Maximum number of containers that may be loaded = 6

a. Density at cube-out = $\left[\frac{7500}{6} - 150\right] \frac{1}{38} = 29 \text{ lbs/ft}^3$

b. Probability of cube-out = $\frac{(29 - 5)}{(40 - 5)} = .685$

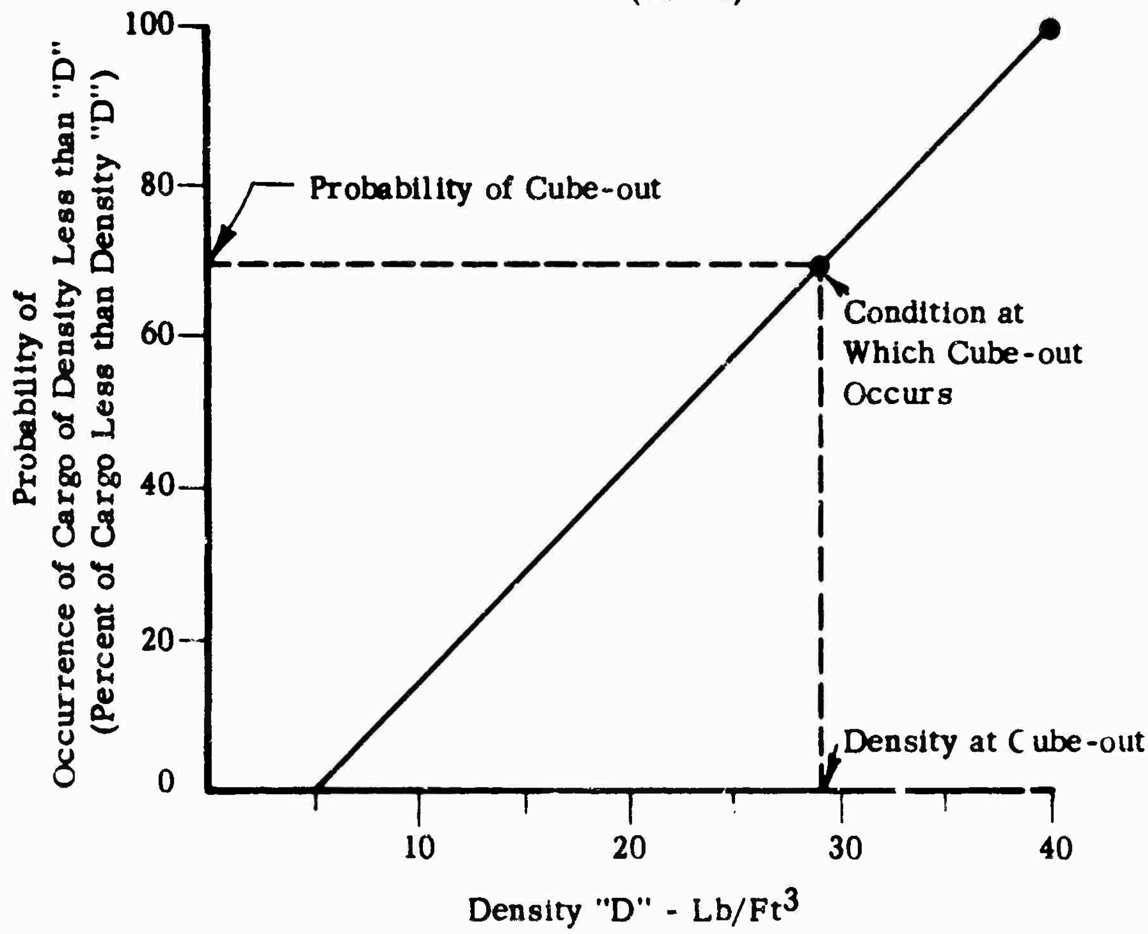

FIGURE 9 EXAMPLE OF CUBE-OUT DENSITY AND PROBABILITY CALCULATION

limit. Consequently, a loss of cargo capacity of 1500 lbs is sustained. A step-function loss may be expected with loads that do not "cube-out" the vehicle. Since Army trucks are expected to "cube-out" in the majority of loadings, the step-function loss is of concern chiefly in the aircraft. It depends on the weight of the containers to be loaded and the cargo capacity of the aircraft, both of which will vary. In order to compare the step-function loss of different containers, aircraft cargo capacity is fixed and the influence of the container's capacity is studied.

Similar to the cube-out loss, the step-function loss varies with the varying density of the cargo. A certain proportion of containers will be loaded with material of such high density that they will weigh the specified maximum weight before they are fully loaded. However, when the density is lower the containers may be filled completely and may have a total weight over a wide range. However, since the cargo density is described with an assumed probability distribution it is possible to calculate the probability that a step-function loss occurs. Likewise, an expected amount of step-function loss, or the average loss of this type over a long period of time, can be calculated.

Figure 10 shows an example of varying cargo density for a certain container in a particular vehicle and shows the number of containers that can be loaded into that vehicle when filled with cargo of density varying across the assumed range. The vertical distance between the continuous curve and the stairstep curve is the step-function loss for the container specified when filled with cargo of the density on the abscissa.

The importance of the step-function loss consideration is reduced to the extent that the following situations exist when an aircraft is loaded.

> Cargo of more than one type, and hence containers of different total weights, are available to be loaded into the aircraft. This allows a degree of freedom of choice when attempting to load to meet the aircraft capacity.
>
> Noncontainerized cargo is available for loading with the containers--allowing freedom to adjust the total cargo load to meet the aircraft weight capacity.

<u>Conflicting Requirements</u>

It is clear from consideration of the evaluation criteria that for different reasons one might prefer to have either a large or a small container in an air transportable

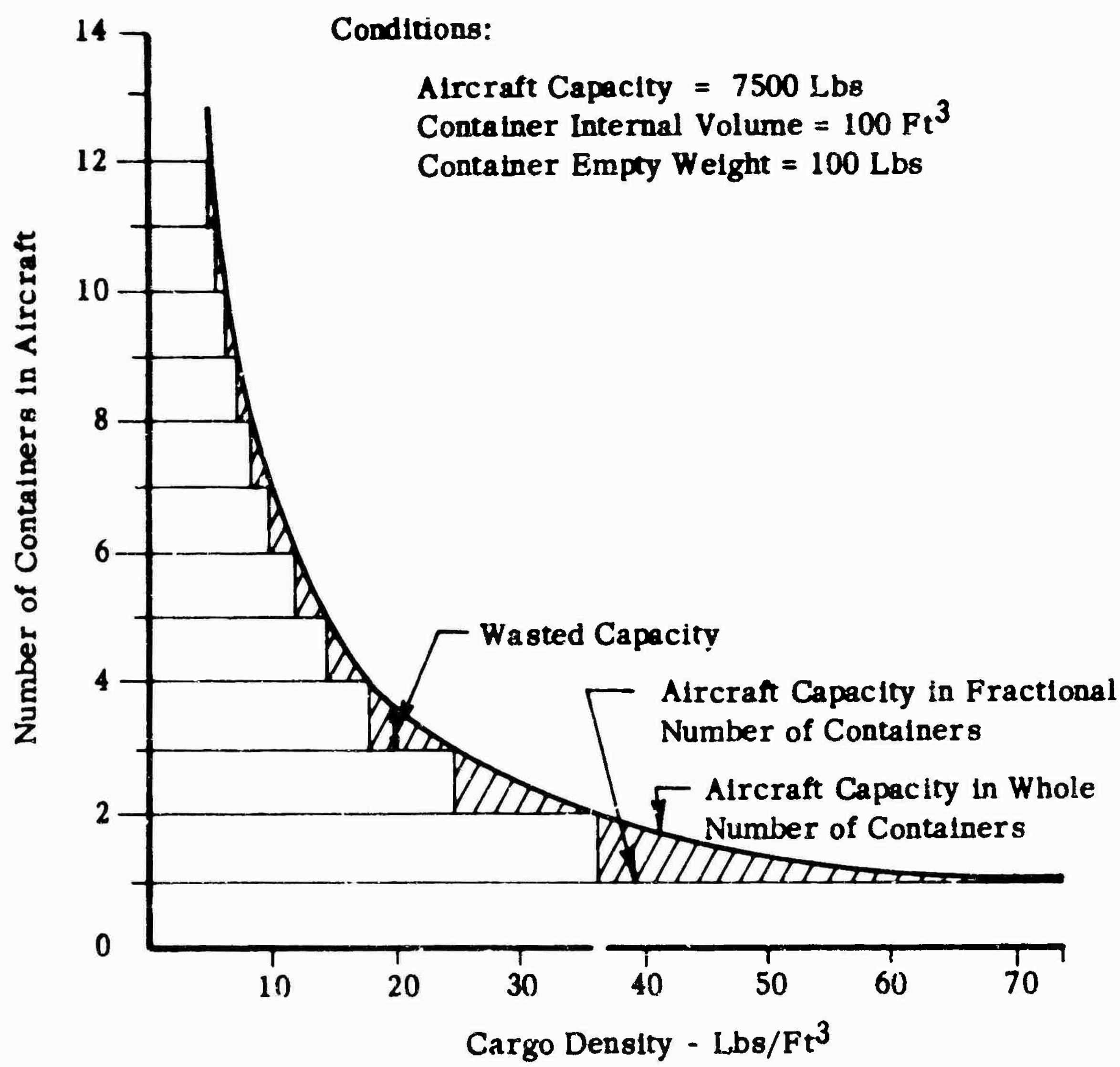

FIGURE 10 EXAMPLE OF STEP-FUNCTION LOSS

cargo system. As may be shown by simple geometry, a container with 1-inch walls, a 4-inch base, and smaller than 3 feet on a side results in very low volumetric efficiency. Weight efficiency in like manner decreases for small containers. Also, a lower stowage factor can be expected for small internal volume containers. For these reasons it would be desirable to have as large a container as possible. However, the larger container is more difficult to fit into vehicles of different sizes and shapes. Similarly, the larger container has greater weight for a particular cargo density, and the step-function loss is increased. Since the 3/4-ton truck effectively places a 2000-lb upper limit on the weight of the cargo and container, it is necessary to have a container small enough so that it does not too frequently reach a total weight of 2000 lbs before being filled. When this occurs, a waste of space inside the container is experienced, some type of dunnage is required, and the weight efficiency of the container as a cargo carrying element is reduced.

Evaluation Methodology

In order to determine the container size meeting the developed requirements that is optimum with respect to the evaluation criteria, it was necessary to calculate the values of the evaluation criteria for a large number of possible sizes. In addition, it was desirable to investigate the sensitivity of each of these criterion to changes in container dimensions and to changes in initial assumptions such as container material weight, cargo density, and methods of stowing the containers in the vehicle cargo spaces. For the purpose of rapid evaluation of many container sizes under variation of the several assumed variables, a computer program was written in FORTRAN for the IBM 1401 computer. This program allowed evaluation of any container size under any chosen set of exterior conditions. Variables or exterior conditions that were set for each evaluation calculation were as follows:

Container wall thickness

Container material density

Container base height

Cargo density, both maximum and minimum

Specified maximum weight of the container and contents

Weight capacities of the different Army aircraft and trucks

Input to the computer program consisted of height, width, and length dimensions of a candidate container, and a card representing a column of a "fit" matrix which contained the maximum number of that particular container that could be loaded in each aircraft or truck. The computer program then calculated the internal volume of the container, the container volumetric efficiency as defined above, and weight efficiency. Likewise, the internal stowage loss, the expected or average unoccupied space due to loading to the maximum weight, and the expected loaded weight of the container are calculated for each container. In addition, the program computed the probability that the container weighed the specified maximum weight, as well as the probability that the container would cube out in each of the six vehicles. The step-function loss and the cube out loss to be expected with that container were calculated for each of the six vehicles. An example of the print-out of one calculation run with this program is enclosed as Appendix I.

Sizes Considered

Initially, a wide variety of container shapes and sizes were considered. Restrictions placed by various elements of the logistic system, discussed above as developed requirements, may be summarized as follows:

> The container should be right rectangular.
>
> The container should be assembleable into 108- by 88-inch modules.
>
> The container should be no more than 70 inches tall, and have a base less than approximately 45 by 63 inches (the CV-2 overhead clearance and the 3/4-ton truck bed dimensions, respectively).

Two basic methods of meeting the requirements that containers be joinable to a total dimension of both 108" and 88" are possible. In the simplest method the containers fit exactly in a 108" x 88" block as in Figure 11a. More size freedom is available when containers are arranged in an irregular manner such as in Figure 11b. Several of these irregular arrangements were first evaluated with the computer program and found to be of no significant advantage over the simpler arrangement of Figure 11a. The more irregular arrangements have the added disadvantages that they require specific orientation before joining, they require that the joining mechanism be capable of fastening the containers together at more than one specific point, and they cannot be joined conveniently to form a module less than the 108" x 88" size. For these reasons, only simple divisions of the basic 108" x 88" rectangle were considered. The following eight container sizes showed promise of meeting all constraints, with good performance characteristics. Numbers 5, 7, and 8 in Table 4 do not, however, meet the requirement of fitting in the 3/4-ton truck. They are included in order to illustrate the effect of that constraint.

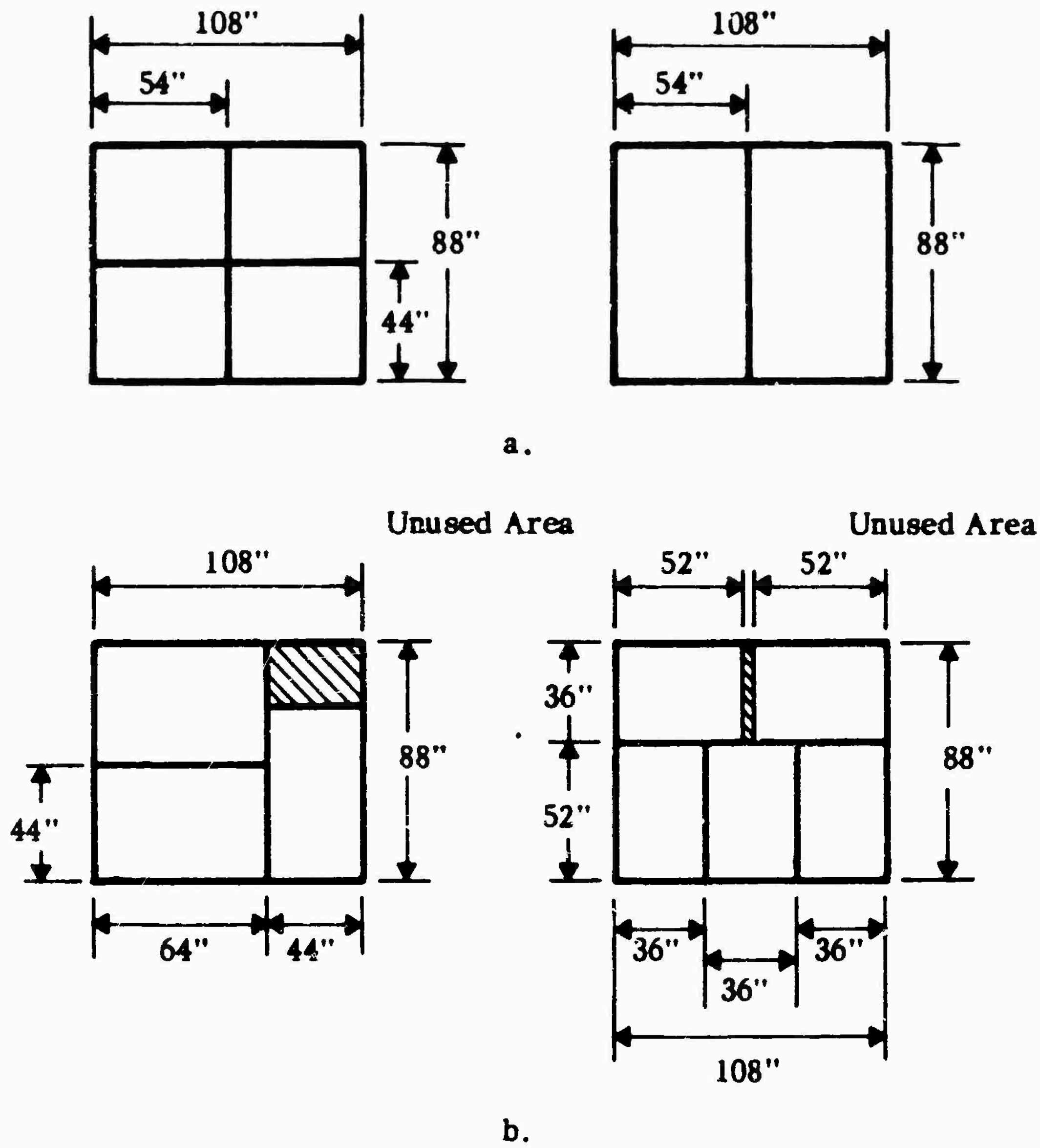

FIGURE 11 PLAN VIEW OF FOUR POSSIBLE ARRANGEMENTS OF CONTAINERS TO MATCH THE 463L MASTER PLATFORM SIZE

TABLE 4

EXTERNAL DIMENSIONS OF CONTAINER SIZES EVALUATED

Candidate Container	External Dimensions Height (Inches)	Width (Inches)	Length (Inches)
1	50	36	44
2	35	44	54
3	50	44	54
4	60	44	54
5	35	54	88
6	70	44	54
7	50	54	88
8	60	54	88

These eight sizes chosen for final analysis and comparison result from the following considerations:

1. 36- x 44-inch base--fits six to the 463L master platform (88" x 108") dimensions.

2. 44- x 54-inch base--fits four to the 463L master platform (88" x 108") dimensions.

3. 54- x 88-inch base--fits two to the 463L master platform (88" x 108") dimensions.

4. 35-inch height--fits all Army aircraft when stacked two high.

5. 50-inch height--included as being comparable to current 40 x 48 pallet loads.

6. 60-inch height--maximum height that allows double stacking in 463L Air Force aircraft.

7. 70-inch height--maximum height that fits in all Army aircraft.[1]

Results of Evaluation

More than 100 combinations of container internal and external dimensions were evaluated by the computer program. Results of the evaluation of the eight selected sizes are shown in Table 5. General results from all of the calculation runs may be summarized as follows:

Volumetric efficiency increases with increasing container size, but does not change sharply on the range of internal volumes considered--from 38 to 145 ft^3. The average increase in efficiency was about 2.3% per 10 ft^3 increase in internal volume.

Expected, or average, loaded weight increases less rapidly than increasing internal volume.

The step-function loss, in like manner, increases sharply with increasing internal volume.

Cube-out loss for Army aircraft varies sharply for the eight containers chosen. This fluctuation is caused by the manner in which each container fits into the three Army aircraft, which sets the maximum number of containers that can be loaded into each aircraft.

The probability of occurrence of empty space in a container, caused by reaching the specified maximum weight, is zero for the smaller containers. This probability begins to increase for internal volumes greater than about 55 ft^3.

Volumetric efficiency decreases rapidly with increasing container wall thickness--the volumetric efficiency for a 1.5-inch wall thickness would be approximately 10% lower than the values shown in Table 5, calculated for a 3/4-inch thickness.

---

1 The 70-inch height was chosen as the tallest container that may be loaded into the CV-2 aircraft (see Table 2). Before detailed design is undertaken of this container, careful study and measurement of the loading hardware and compartment entrance measurements of the CV-2 would be required. It is necessary that, at any possible ramp angle, the chord from the center of the point of rotation on the container's 54-inch bottom edge to the leading upper edge may be rotated about the handling hardware's point of entry rotation and still clear the closest overhead obstruction.

TABLE 5

RESULTS OF EVALUATION OF EIGHT CONTAINERS

Container Number	Internal Volume (ft^3)	Expected Loaded Weight (lb)	Volumetric Efficiency (%)	Weight Efficiency (%)	Stowage Factor	Probability of Vacant Space	For the Three Aircraft: Total Expected Cube-Out Loss	For the Three Aircraft: Total Expected Step-Function Loss
1	38	805	66	84	.79	0.0	779	1217
2	39	821	64	84	.79	0.0	394	1271
3	58	1241	70	87	.83	.05	1348	1702
4	71	1457	74	88	.85	.29	692	1731
5	79	1562	72	87	.87	.40	582	1691
6	84	1602	77	88	.88	.45	330	1702
7	119	1818	82	87	.95	.70	774	NA**
8	145	1900	88	86	NA*	.80	702	NA**

* Results not directly comparable due to large internal volume.

** Step-function loss for the CV-2, and hence the total, is not directly comparable.

The step-function and cube-out losses shown in Table 5 are the sums of the expected values for the three aircraft. Probability of vacant space is also shown, which may be considered as the proportion of the time that a particular container may not be fully packed, due to reaching the 2000-lb limit. The "Stowage Factor" is the internal stowage utilization factor discussed above as an evaluation criterion. Expected loaded weight is the average weight of cargo expected to be carried by the container plus the container weight.

Figure 12 shows container performance in terms of aircraft capacity.[1] The average load expected to be carried by each Army aircraft when loaded with the containers listed in Table 4 is plotted against the internal volume of the containers. The expected load is expressed as a percent of the cargo capacity of each aircraft.[2]

As may be seen from Figure 12, containers numbered 2, 4, 5, 6, and 8 provide both greater than 90-percent weight capacity utilization in the CV-2 and greater than 98-percent weight capacity utilization in the CV-7 and CH-47. Numbers 5 and 8, however, were of the 54- by 88-inch base group, included only for comparison. Since they do not fit the 3/4-ton truck, they will not be considered further.

Container numbers 2, 4, and 6 are preferred on the basis of cargo carrying performance. These three containers have base dimensions of 44" x 54" and are 35", 60", and 70" high. Throughout the remainder of this report they will be identified by their height alone.

---

1 The effect of step-function loss is neglected in Figure 12, because this loss is considered less significant than the cube-out loss, for the reasons outlined on page 29. It should be recognized, however, that in situations where one supply item packed in containers must be loaded into an aircraft with no leeway to add other noncontainerized cargo, some loss will be incurred due to inexact matching of load with container capacity.

2 The points in Figure 12 are connected only for clarity. The connecting lines do not represent performance values for container internal volumes between any two numbered containers.

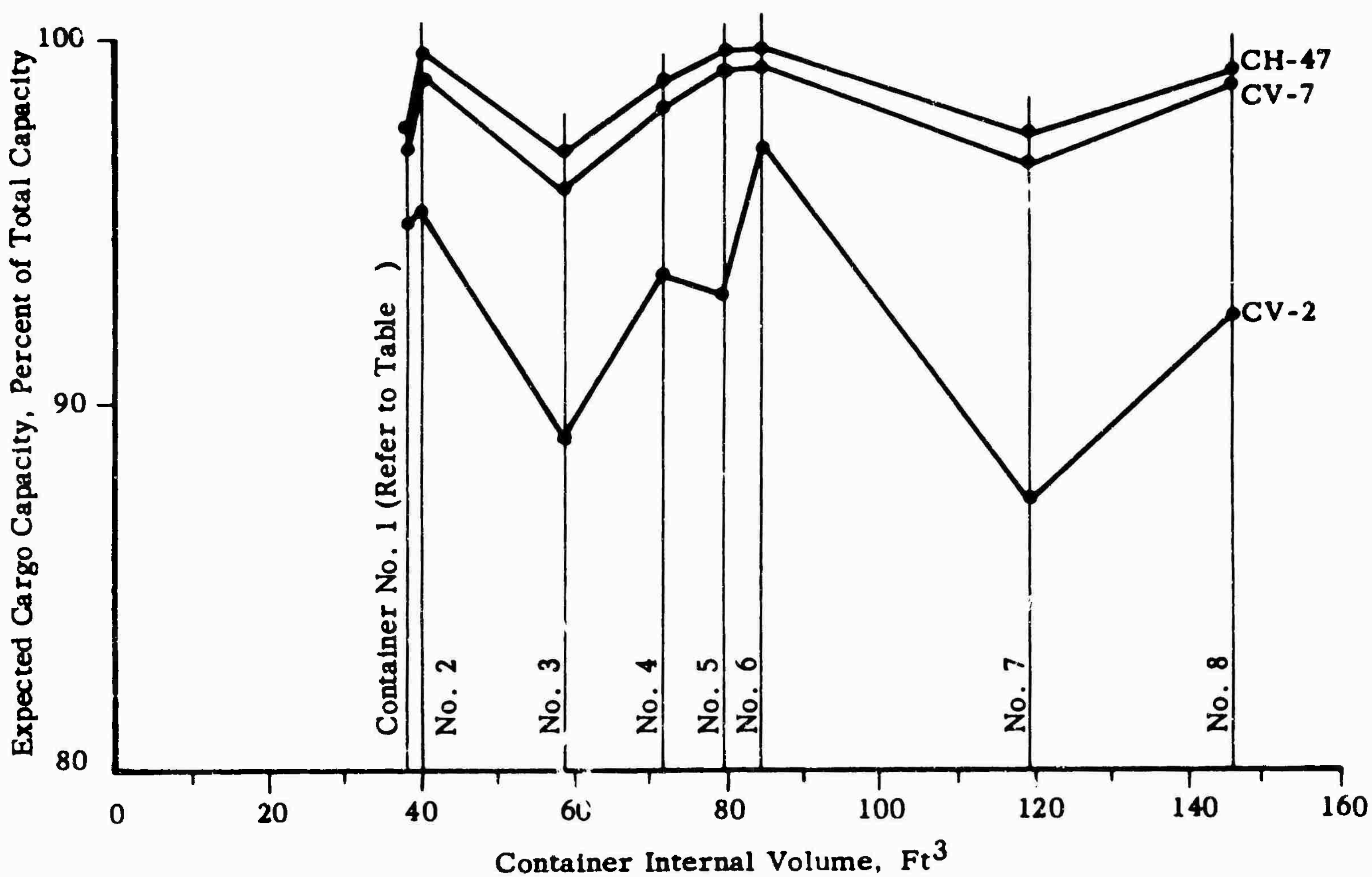

FIGURE 12 EXPECTED CARGO CARRYING CAPACITY OF THREE ARMY AIRCRAFT FOR EIGHT CONTAINER SIZES AS A PERCENT OF AIRCRAFT CARGO CAPACITY

ALLOWABLE CONTAINER WEIGHT

As specified in the statement of work, container weight cannot exceed the weight of level A packing and unitizing materials replaced by the container. Weights of packing and unitizing materials used in the calculations are listed in Table 6.

TABLE 6

WEIGHTS OF PACKING AND UNITIZING MATERIALS[1]

Solid fiberboard, grade V2S	.44 lb/ft^2
Corrugated boxboard, grade V3C	.24 lb/ft^2
Commercial 200# test corrugated board	.15 lb/ft^2
Wooden box for level A pack	1.60 lbs/ft^2
Disposable wooden pallet	75. lbs

The range of allowable weight for three most promising containers selected on the basis of size and carrying capacity is shown in Figure 13. The calculations are based on an average carton size of 1.5 ft^3, and are in close agreement with several studies of the physical size of Army shipments.[2] The amount of packing materials required is not greatly influenced by the size of cartons, however. Figure 14 illustrates the effect on packing material as carton volume changes. The calculation is made for an 84 ft^3 container reduced by the stowage factor, using cartons of equal dimensions (length = width = height). Rectangular cartons would require more material per unit volume; thus calculations based on equi-dimensional cartons are on the conservative side. As shown in Figure 14, the reduction in carton material decreases only 22% as carton size is increased from 1 cubic foot to 2 cubic feet. The effect is less as carton volume is increased further.

The allowable container weight is heavily influenced by the amount and type of packing material replaced. As a criterion for allowable container weight, the packing material in an average load has been estimated to be 10% wooden boxes, 25% V2S carton material and 65% V3C carton material. This proportion has been determined chiefly through observation of the packing materials used at several Army and Air Force depots, plus observation of cargo moving through the MATS system. Using these proportions of packing material, the allowable weight for the three containers considered are shown in the following table.

1 Source of material weights: Boxboard weights from U.S. Army Food & Container Institute; wooden box weights calculated from information obtained at Oakland Army Terminal; and pallet weight obtained from USAAML.

2 Transportation of Subsistence to the Northeast Air Command - MCTC, 1956, Export Packaging Study for Aerial Delivery Planning 7-87-03-004 Aerial Delivery Equipment, September 1954.

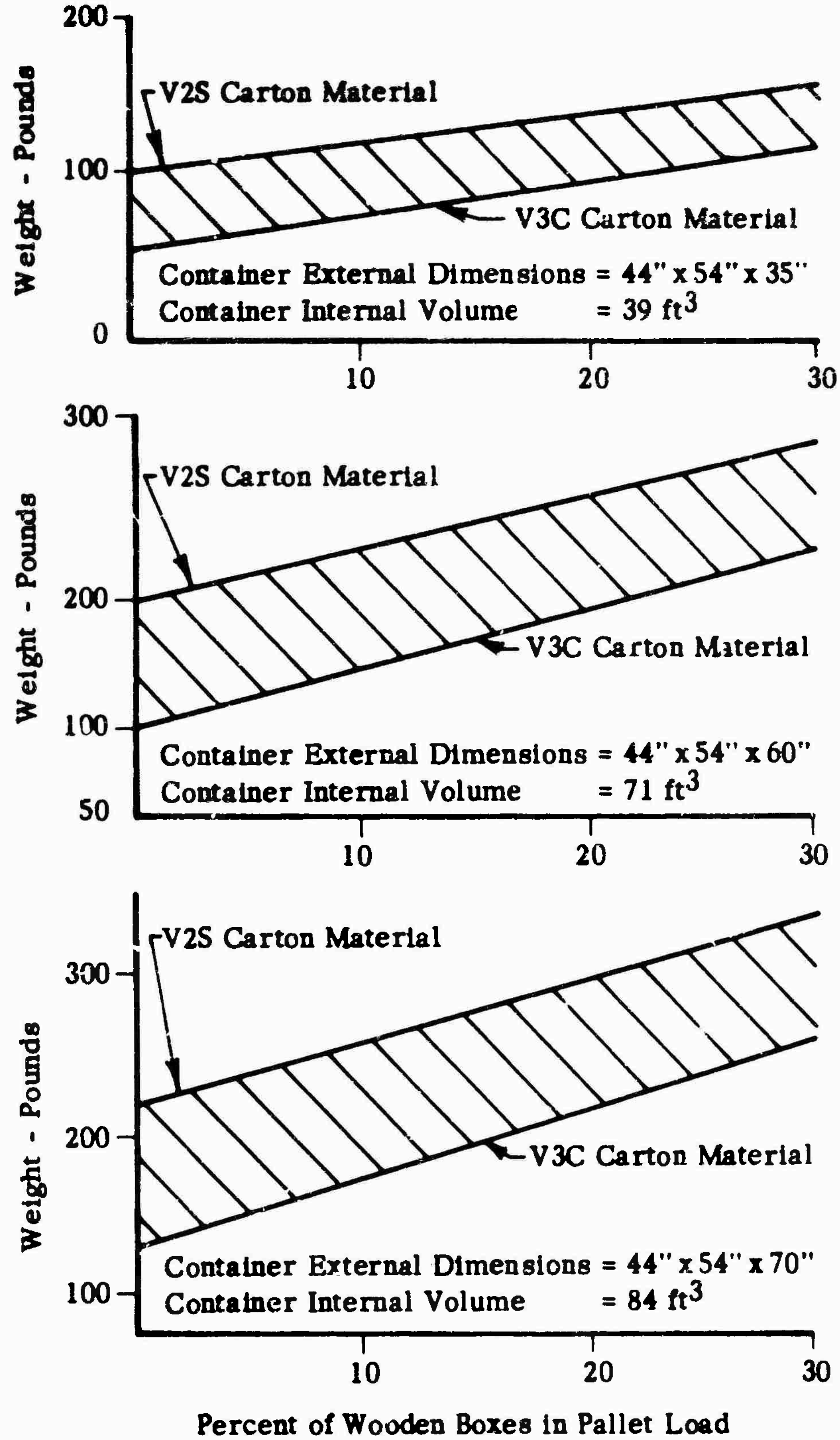

FIGURE 13 RANGE OF ALLOWABLE WEIGHT OF CONTAINER BASED ON REPLACEMENT OF LEVEL A FIBERBOARD, WOODEN BOXES AND PALLET ON EQUIVALENT PALLET LOAD. CALCULATIONS BASED ON CUBIC CARTONS HAVING 1.5-ft^3 EXTERNAL VOLUME

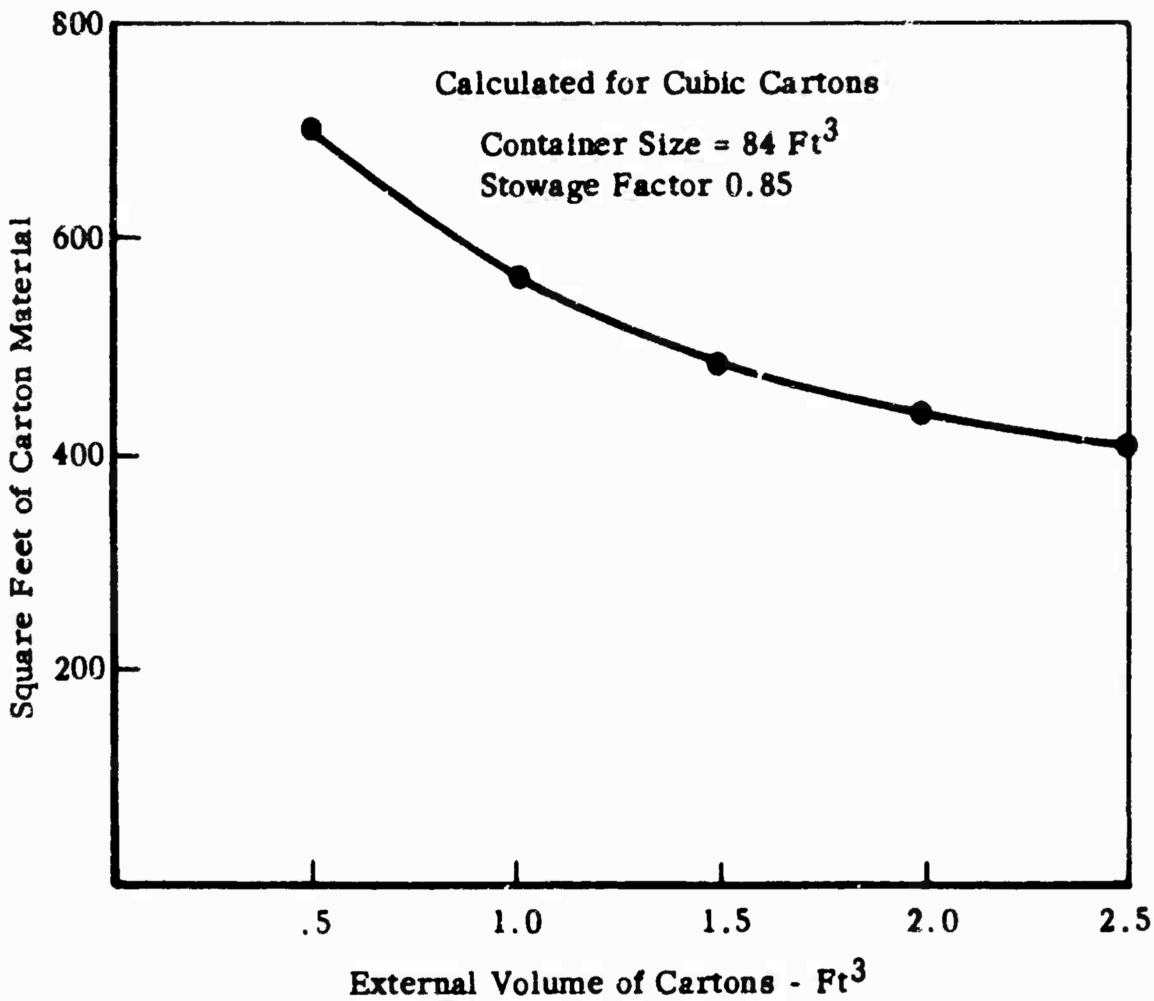

FIGURE 14 RELATIONSHIP OF PACKING CARTON VOLUME TO SURFACE AREA

TABLE 7

ALLOWABLE WEIGHT FOR CONTAINERS BASED ON AVERAGE PALLET LOAD OF 10% WOODEN BOXES, 25% V2S, AND 65% V3C PACKING MATERIAL

Container Size	Container Volume (ft^3)	Allowable Weight (lbs)
44" x 54" x 35" high	39	90
44" x 54" x 60" high	71	165
44" x 54" x 70" high	84	195

CONTAINER EVALUATION BASED ON ALLOWABLE WEIGHT

The allowable weight of 90 pounds for the 35-inch-high container is unreasonably low. It would be extremely difficult, if not impossible, to construct a container of this size to meet the requirements and hold it to a 90-pound limit. Therefore, the 35-inch-high (39 ft^3) container will not receive further consideration. For the 60-inch- and 70-inch-high containers, the estimated allowable weights of 165 pounds and 195 pounds, respectively, appear to be a reasonable target for the air transportable container.

JUSTIFIABLE COST OF CONTAINER

As previously stated, the proposed container system would replace loads unitized on 40" x 48" pallets. In addition, the containers considered have been limited to those sizes which are modular to the 463L platform. This restriction has been imposed because it is recognized that a container system which eliminates the need for carrying the master platform permits substantial cost savings. Although not specifically stated, the requirement for using the empty container for other purposes upon delivery of its contents implies disposing of it after one trip. Accordingly, the container has been considered as a nonaccountable item and justifiable cost has been estimated for a single trip.

In this section, the justifiable container cost is developed by estimating the material, labor, handling, and transportation cost savings resulting from the proposed container system. The 60"- and 70"-high containers are compared to the standard pallet load. A cost estimate for a nonmodular container is included as justification for the original assumption that only modular containers should be considered.

MATERIAL SAVINGS RESULTING FROM CONTAINERIZATION

The cost difference between level A packing plus a disposable pallet and level C packing for containerized supply items has been estimated. Cost elements used for packing operations are shown below.

TABLE 8

COST ELEMENTS FOR PACKING OPERATIONS*

Level A packing in corrugated V3C cartons (includes labor and material)	\$ .75 per ft^3
Level A packing in solid fiberboard V2S cartons (includes labor and material)	.85 per ft^3
Level A packing in wooden boxes (includes labor and material)	1.50 per ft^3
Level C packing in corrugated cartons (includes labor and material)	.50 per ft^3

TABLE 8 (contd)

Cost of 40" x 48" disposable wooden pallet	$2.80

* Packing costs obtained from Oakland Army Terminal. Pallet cost obtained from USAAML.

The range of material cost differences for various combinations of packing methods is shown in Figure 15. Using the same proportions of packing materials as estimated for calculating the allowable weight, the expected cost saving in materials is tabulated in the following table.

TABLE 9

ESTIMATED MATERIAL SAVINGS PER CONTAINER BASED ON AVERAGE PALLET LOAD OF 10% WOODEN BOXES, 25% V2S, AND 65% V3C PACKING MATERIAL

Container Size	Container Volume	Material Cost Savings
44" x 54" x 60" high	71 ft^3	$20.00
44" x 54" x 70" high	84 ft^3	$24.00

TRANSPORTATION, HANDLING, & LABOR COST OF PALLET & CONTAINER SYSTEMS

Cost elements for packing and transporting a unitized load (pallet or container) through the ALOC are given below.

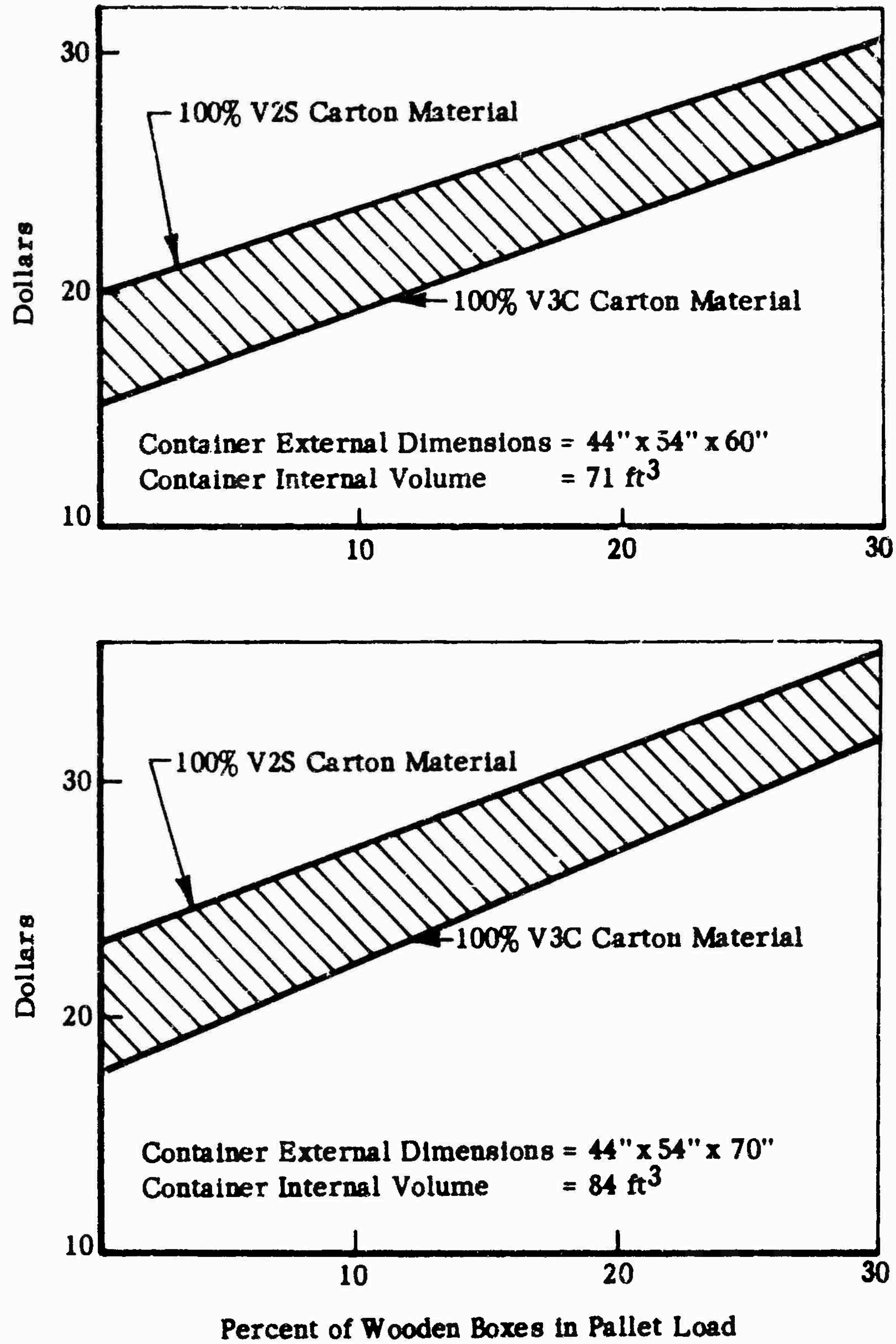

FIGURE 15 RANGE OF MATERIAL COST DIFFERENCE WHEN THE PALLET, LEVEL A FIBERBOARD, AND WOODEN BOXES ARE REPLACED BY A CONTAINER. CALCULATIONS BASED ON CUBIC CARTONS HAVING 1.5-ft^3 EXTERNAL VOLUME

TABLE 10

MAJOR COST ELEMENTS FOR TRANSPORT SYSTEM

Labor rate for manual operations	$3.00 per hour
Pallet buildup and container filling rate	2000 lbs/man-hour
Forklift truck operating cost (includes labor cost of operator)	$4.00 per hour
Surface transport in CONUS	$ .02 per ton mile
MATS airlift	$ .18 per ton mile within CONUS plus per pound rate to designated overseas destinations.
Theater airlift	$ .18 per ton mile
Army airlift CV-2 cost per operating hour	$260.00

A cost comparis of labor, handling, and transportation has been made for a typical standard Army palletized load and for two containers. The 70" container is considered two ways: (1) fitting the 463L rail and (2) requiring 463L platforms and nets. The basis for cost comparison is shown in the following table.

TABLE 11

BASIS FOR COST COMPARISON FOR MOVING PALLET AND CONTAINER THROUGH THE ALOC FROM CONUS TO BATTALION

Pallet	Pounds
Weight of cargo packed to level C	1410
Weight of extra packing material required for level A protection	120
Pallet weight	75
TOTAL WEIGHT	1605
Container (44" x 54" x 70" high, 84 ft^3)	
Weight of cargo packed to level C	1410
Weight of container	195
TOTAL WEIGHT	1605
Container (44" x 54" x 60" high, 71 ft^3)	
Weight of cargo packed to level C	1285
Weight of container	165
TOTAL WEIGHT	1450

In the above table, the weight of cargo is considered to be packed to level C protection in each case. The actual weight of cargo per pallet load is increased by the extra weight of packing material required for level A protection.

Many of the handling operations are considered to be equal for pallets and containers. Although estimates have been made for all major handling operations, they cancel out in the comparative cost figures.

For comparative purposes, in the transportation segments where the 463L platform and nets must be used, the chargeable weight of the platform and netting (90 lbs) has been included as payload. Hence, the transportation cost for these segments is calculated by including the weight of the required 463L equipment which is airlifted.

Transportation charges for MATS movement in CONUS are estimated ton-mile rates calculated from rate tables for special assignment missions.[1] MATS transportation charges to overseas destinations were obtained directly from rate tables. These rates include the cost of terminal handling. Since the comparative cost figures include estimates for terminal handling, the total transportation cost is in error by a small amount. The analysis serves to point out the differences in handling operations and costs for the various unitizing methods compared.

The cost of Air Force Theater airlift was assumed to be equal to MATS special mission rates because no figures for this segment of the ALOC were readily available. Transport cost for the Army airlift segment is based on $260 per operating hour for the CV-2 aircraft.[2]

Direct labor and forklift-truck operating costs are based on comparable industrial operations.

Figure 16 shows a detailed flow diagram of a palletized load of Army cargo through the ALOC from CONUS to battalion level overseas. Figure 17 is an equivalent flow diagram for containers which are modular with the 463L platform.

Table 12 gives a summary of costs estimated for the delivery of comparable pallet or container through a typical ALOC from the United States to an overseas battalion area. The example used is the European theater.

COST SAVINGS OF CONTAINERIZED SYSTEM IN ALOC

The results of labor, handling, and transportation costs for pallet and container systems show that there is no saving unless the container replaces the 463L master platform when shipped through the ALOC. The results tabulated in Table 12 also show the cost per pound to ship cargo in the 60"- and 70"-high container to be equal, assuming container weight to be 165 lbs and 195 lbs, respectively.

The total savings estimated for a 70"-high, 84-ft^3 container over a standard pallet load when moving through the ALOC from CONUS to the European theater is $33.95 ($679.15 minus $645.20).

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1 AFR 76-11 Military Airlift Common User Tariff Rates, April 1964.

2 Maintenance & Operating Cost for Army Aircraft #335-3, U.S. Army Aviation Command, August 1963.

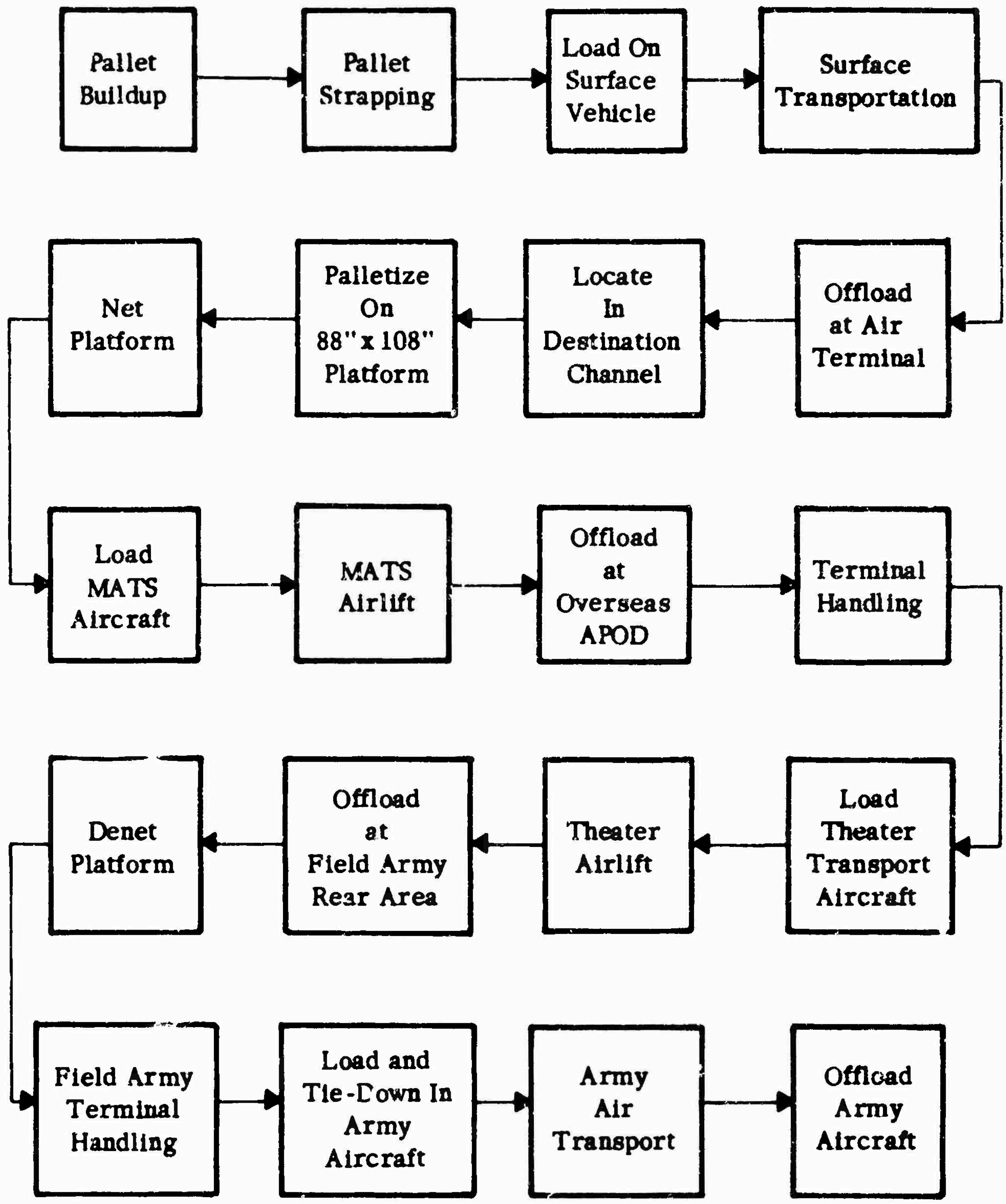


FIGURE 16 DETAILED FLOW DIAGRAM OF UNITIZED ARMY PALLET (40" x 48") THROUGH THE ALOC FROM CONUS TO BATTALION

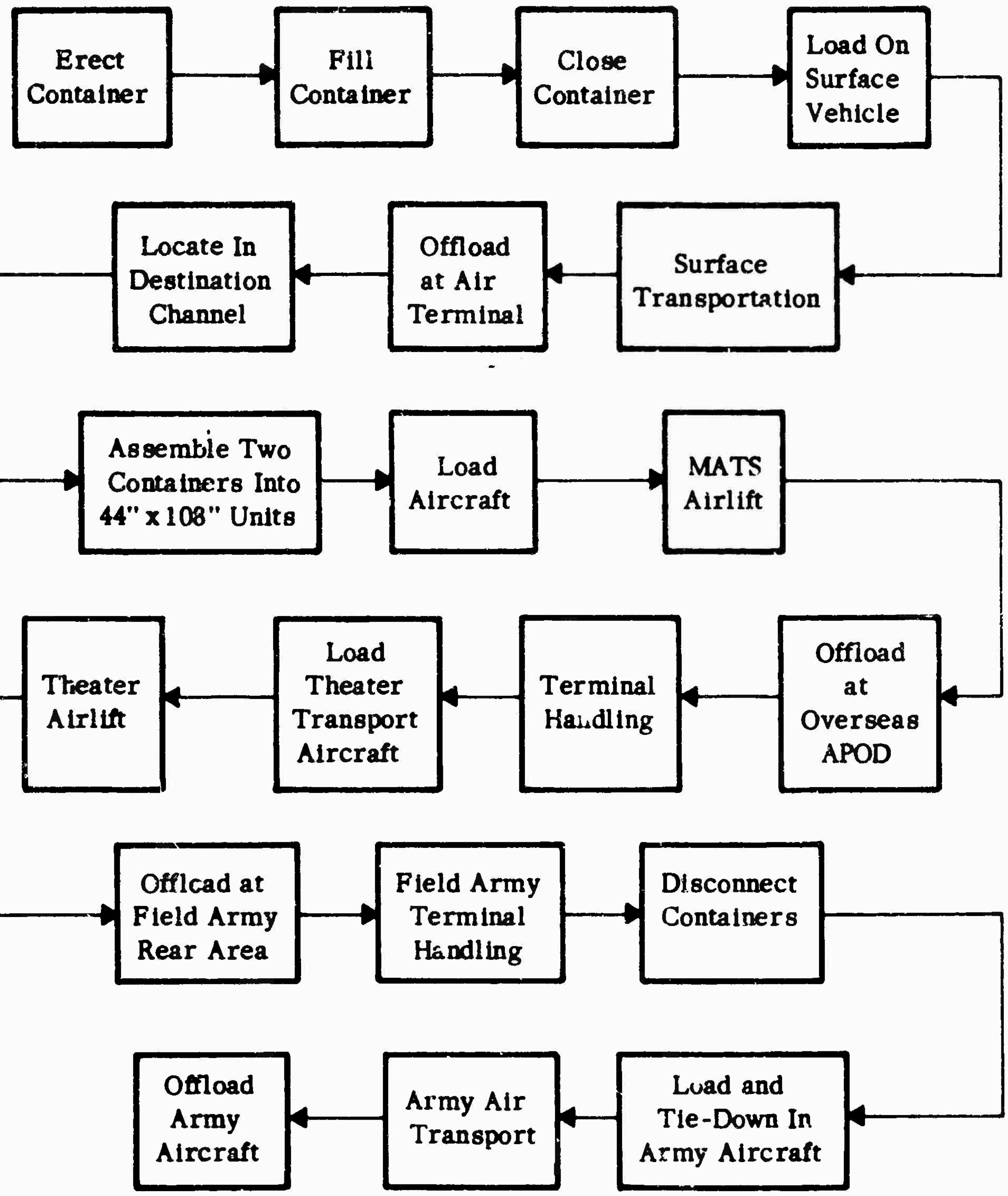


FIGURE 17 DETAILED FLOW DIAGRAM OF AN ARMY CONTAINER MODULAR WITH 463L THROUGH THE ALOC FROM CONUS TO BATTALION.

TABLE 12

COST ESTIMATE OF TRANSPORTATION, HANDLING, AND LABOR FOR ARMY PALLETIZED LOAD AND THREE CONTAINERS THROUGH A TYPICAL ALOC FROM CONUS TO THE EUROPEAN THEATER

	Pallet 40"x48"	Container(84 ft^3) 44"x54"x70"high Modular to 463L rail system	Container(84 ft^3) Equivalent volume but requiring 463L platform for Air Force handling	Container(71 ft^3) 44"x54"x60"high Modular to 463L rail system
Pallet buildup or container loading	$ 2.85	$ 3.15	$ 3.15	$ 3.00
Handling and surface transportation in CONUS	3.40	3.20	3.40	3.20
MATS airlift (1000 miles within CONUS then to France)	575.50	545.75	575.50	493.00
Overseas handling and transportation (500 mi) by Air Force	77.05	72.65	77.05	65.70
Overseas handling and transportation (50 mi) by Army	20.35	20.45	20.35	20.45
TOTAL COST	$679.15	$645.20	$679.45	$585.35
Cargo weight carried	1410#	1410#	1410#	1285#
Cost/Pound	$.482	$.457	$.482	$.457

INFLUENCE OF ALOC LENGTH ON COST SAVINGS

Of the estimated $33.95 cost savings for the 70"-high container, $22.75 is attributable to the MATS segment of the ALOC. This is the largest single factor; hence, the expected total savings is a function of the length (and cost) of this segment. Table 13 illustrates the relationship of the MATS intercontinental segment to savings attainable. For this calculation, all other costs are assumed to remain fixed.

TABLE 13

TRANSPORTATION, HANDLING, AND LABOR SAVINGS FOR THE 44"- x 54"- x 70"-HIGH CONTAINER OVER PALLETIZED LOADS AS A FUNCTION OF LENGTH OF MATS SEGMENT

MATS Intercontinental Segment		Estimated Total Cost		Estimated
Origin	Destination	Pallet	Container	Savings
East Coast APOE	Paris, France	$ 681	$ 647	$34
	Naples, Italy	808	767	41
	Athens, Greece	886	839	47
West Coast APOE	Tokyo, Japan	856	811	45
	Taipei, Taiwan	978	929	49
	Bangkok, Thailand	1,083	1,028	55
	New Delhi, India	1,258	1,191	67

SAVINGS ON DEPRECIATION OF MASTER PLATFORM

A small saving will accrue to the Air Force due to elimination of the master platform when airlifting Army containers. This is the saving on the platform depreciation, which can be considered as a saving on initial investment.

No accurate statistics are available from the Air Force regarding the expected life of master platforms. The consensus of those people questioned was that the useful life of platforms would be at least 300 trips. The cost of master platforms plus netting is approximately $300. Since a container would replace one-fourth of a master platform, the saving which would result from not using the platform would be approximately $.25 per container per trip. This saving is neglected in justifying the container cost.

JUSTIFIABLE CONTAINER COST

The container cost can be justified by two elements of savings: (1) level A packing and unitizing materials replaced, and (2) transportation, handling, and labor savings which result from substituting the container for a palletized load. The sum of these possible savings is shown in the following table.

TABLE 14

RANGE OF EXPECTED SAVINGS PER CONTAINER
(44" x 55" x 70", 84 ft^3)
WHEN TRANSPORTED TO OVERSEAS BATTALION

Material	Transportation, Handling, & Labor	Total
$24.00	$34.00	$58.00
24.00	67.00	91.00

Based on the foregoing estimates, a container cost of $58.00 is justifiable for the 44" x 54" x 70" high container.

SUMMARY OF CONTAINER SELECTION RESULTS

Results of the analysis for the eight container candidates which were listed in the "Size and Carrying Capacity" section are summarized in Table 15. The containers have been analyzed with respect to their performance as a cargo carrying device and their performance when being transported in the specified surface vehicles and aircraft. Allowable weight and justifiable cost has been estimated for those containers which met the criteria established in the "Size and Carrying Capacity" section.

Obviously, the container weight, cost, wall thickness, and base height should be held to a minimum consistent with good engineering design. The wall-thickness and base-height dimensions have been selected as being reasonable. The resulting weight and cost figures also seem to be reasonable to achieve. The preferred container (No. 6) has the following developed dimensions, weight, and cost.

Outside dimensions	=	70" high x 44" wide x 54" long
Wall thickness	=	3/4 inch
Base height	=	4 inches
Allowable weight	=	195 pounds
Justifiable cost	=	$58.00

TABLE 15

SUMMARY OF SIZE CHOICE ANALYSIS

Container No.	Dimensions H	W	L	Internal Volume	Results of Analysis
1	50"	36"	44"	38 ft^3	Rejected because of greater cube-out loss and complicated fastening arrangement due to one-sixth master platform size.
2	35	44	54	39	Rejected due to unreasonably low allowable weight and complicated fastening arrangement when containers would be stacked two high.
3	50	44	54	58	Rejected on the basis of higher cube-out loss and lower aircraft space utilization than higher containers.
4	60	44	54	71	This is the second choice for an acceptable container. Performance characteristics are nearly equal to the 70"-high container.
5	35	54	88	79	Container does not fit the bed dimensions of the 3/4-ton Army truck. It was included in the analysis for comparative purposes only.
6	70	44	54	84	Highest expected aircraft cargo capacity utilization compared to other containers considered. Allowable weight = 195 lbs Justifiable cost = $58.00
7	50	54	88	119	Rejected because container does not fit bed dimensions of 3/4-ton Army truck.
8	60	54	88	145	Rejected because container does not fit bed dimensions of 3/4-ton Army truck.

OPTIMIZATION OF ARMY AIRCRAFT CAPACITIES

In order to assess the degree of optimization or maximization of aircraft capacity attained by the selected container, it is necessary to define the relevant measure of aircraft capacity. Aircraft may be considered to have cargo capacity of a certain number of pounds, or of a certain number of cubic feet of cargo compartment.

WEIGHT CAPACITY UTILIZATION

The size evaluation carried out in the above sections was concerned mainly with utilization of aircraft weight capacity. In Army aircraft, the weight limit is of much greater concern than is the space limitation; planes are more often found to "gross out" than to "cube out." This may be illustrated by considering the fact that if the CV2 Caribou were filled with cargo of an average density of 22 lbs per cubic foot, it would contain over three times its maximum weight capacity. Incomplete utilization of aircraft weight capacity, expressed as cube-out loss, is less for the chosen container than for any of the other sizes considered. Consequently, the size chosen was considered to provide the maximum realizable utilization of Army aircraft weight capacity.

SPACE UTILIZATION

Although of secondary importance to weight capacity utilization in the specified Army aircraft, the cargo space utilization becomes important when low density cargo is to be transported. The following section demonstrates the fit of containers in the specified Army aircraft.

TRANSPORT FIT AND COMPATIBILITY

Figures 18 and 19 show plan and elevation views of the transport fit of the preferred container in three Army aircraft. The arrangement of 12 containers shown to fit the CH-47 Chinook allows only a 2-inch side clearance; hence, it would be possible only if special tiedown fittings were used. Eight containers will fit the aircraft easily if placed in a single row with the 54" dimension across the cargo compartment similar to the method shown for the CV-2 Caribou. With this configuration, conventional tiedown fittings can be used.

The transport fit for the CV-7 Buffalo is premised on the installation of the 463L roller and rail system. The side clearance in this aircraft is 4", which also would require special tiedown fittings if the 463L system were not used. Eight containers will fit in a single row in the same manner as shown for the CV-2. In both the CV-7 and the CH-47, the weight of eight containers loaded to the average expected gross weight of 1600 lbs is more than the capacity of the aircraft.

Figure 20 shows the plan view of the container fit in specified Army surface vehicles. The container will fit the M-36 and M-37 trucks only with the canvas top removed. No elevation view is shown for these vehicles.

COMPATIBILITY WITH FIELD ARMY MATERIALS HANDLING EQUIPMENT

The 70" x 44" x 54" container size chosen is compatible with current and probable future Army field materials handling equipment. All equipment currently used with the standard 40" x 48" x 54" palletized load is capable of handling the container, since its base allows four-way fork entry, its dimensions are closely comparable to the pallet load, and its maximum weight is less than many standard pallet loads.

Table 16 lists several of the Army field materials handling equipment that may be employed in future field operations and their important characteristics[1], and the container arrangements they are capable of handling.

1 Army Air Logistical Study, Contract DA44-177-T6-754, December 1962, p. 159.

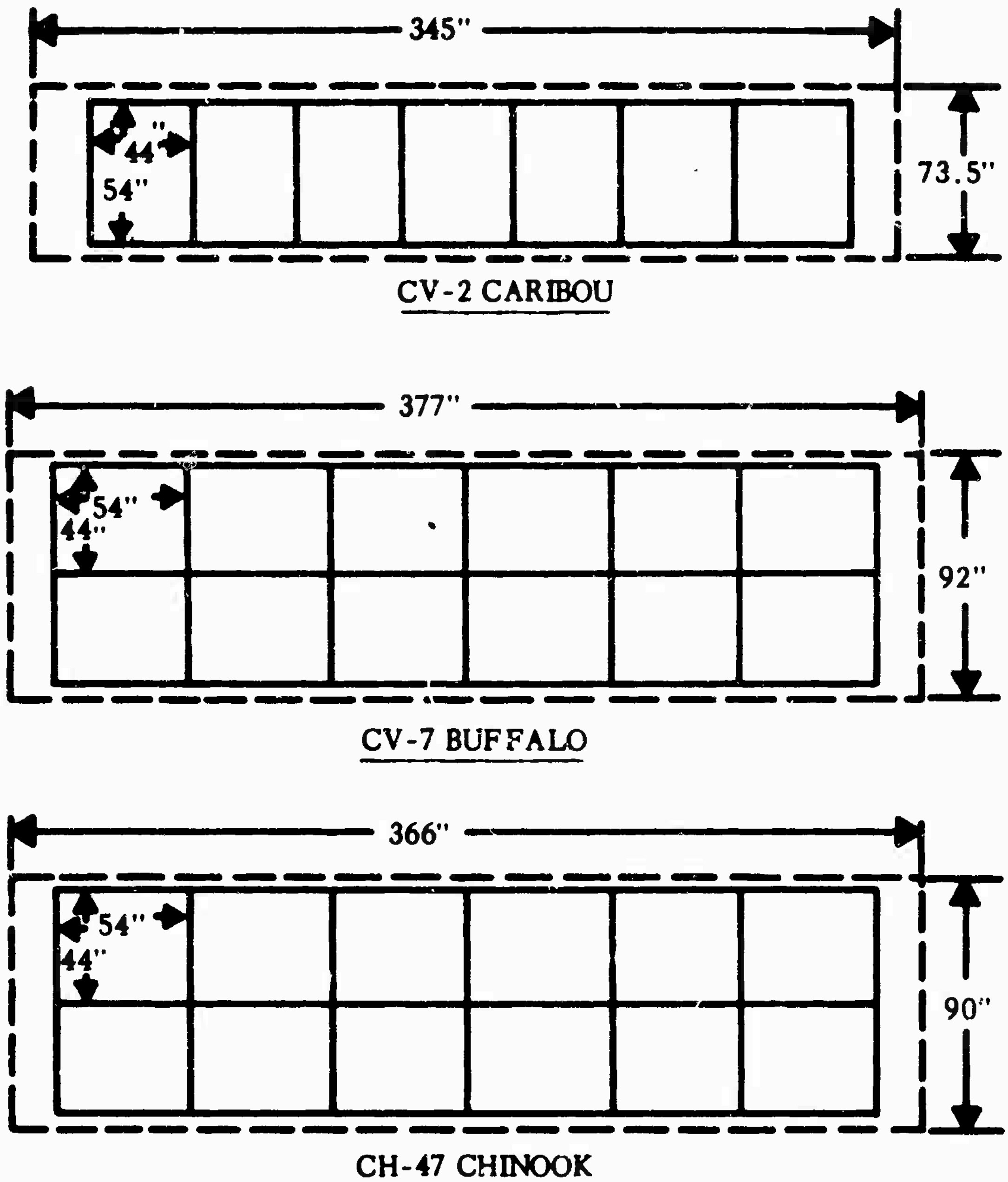
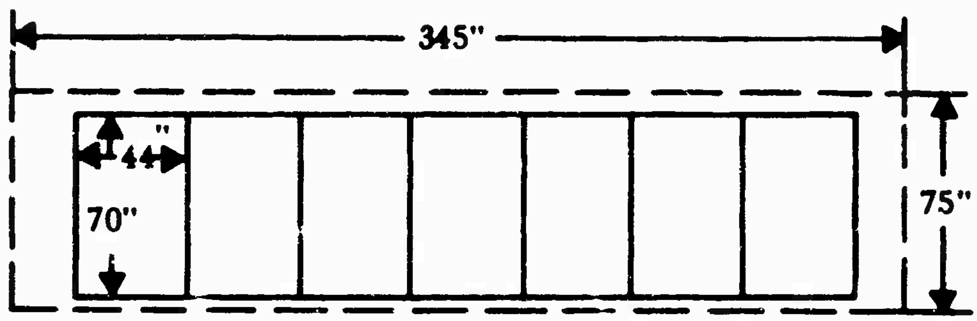
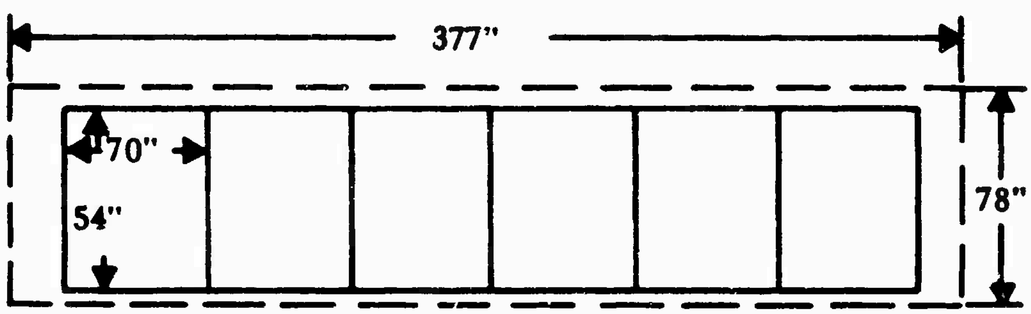


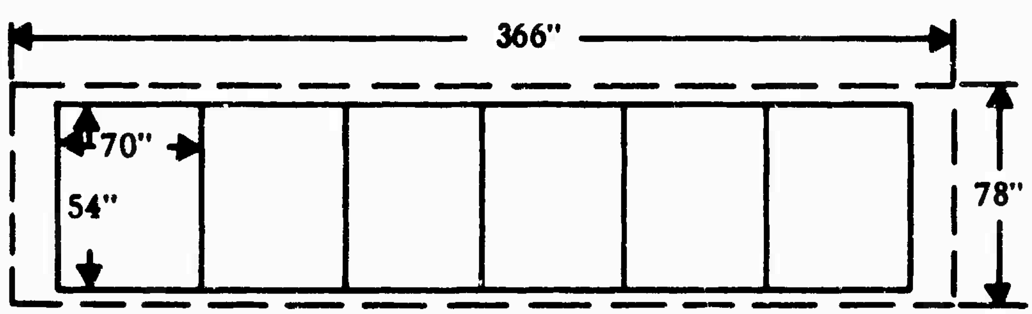
FIGURE 18 PLAN VIEW OF TRANSPORT FIT OF CONTAINERS WITH 44" x 54" BASE IN ARMY AIRCRAFT



CV-2 CARIBOU

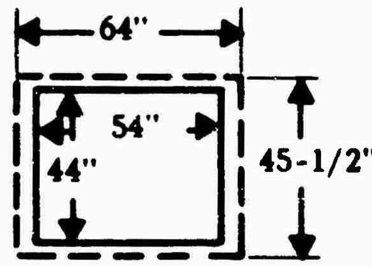


CV-7 BUFFALO

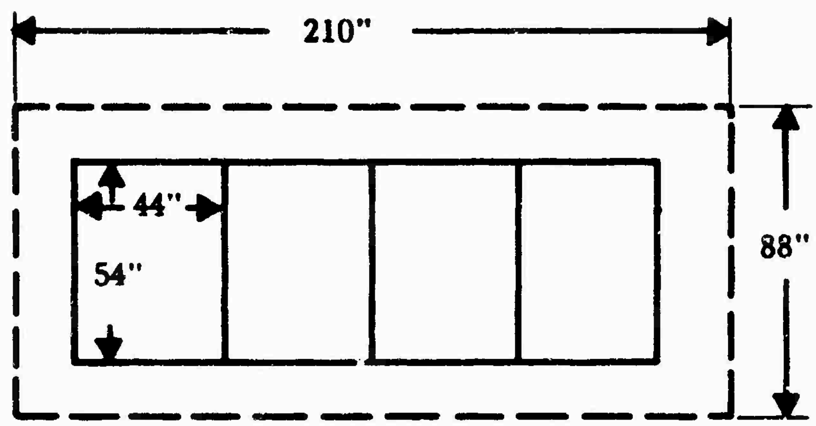


CH-47 CHINOOK

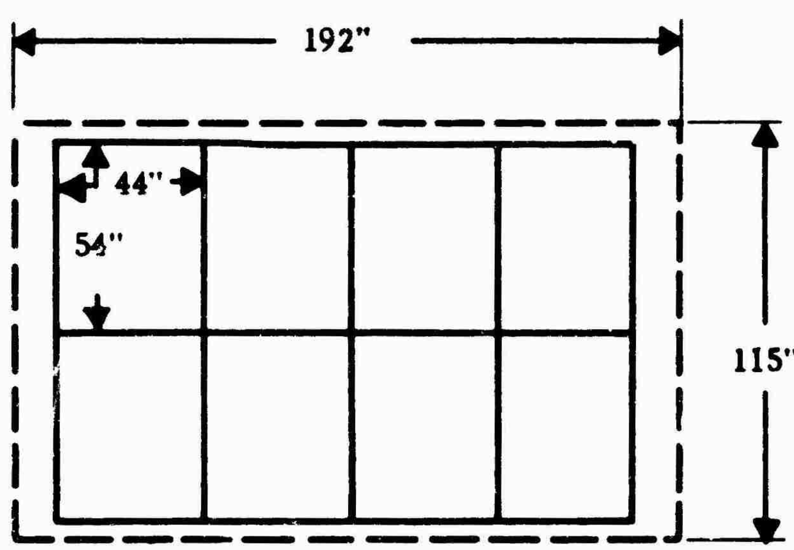
FIGURE 19 SIDE ELEVATION VIEW OF TRANSPORT FIT OF 44" x 54" x 70" CONTAINER IN ARMY AIRCRAFT



M-37 (3/4 Ton) TRUCK



M-36 (2.5 Ton) TRUCK



M-172A1 (25 Ton) TRAILER

FIGURE 20 PLAN VIEW OF TRANSPORT FIT OF CONTAINERS WITH 44" x 54" BASE IN ARMY SURFACE VEHICLES

TABLE 16

CHARACTERISTICS OF FIELD ARMY MATERIALS HANDLING EQUIPMENT AND CONTAINER LIFTING CAPABILITIES

Vehicle	Rated Load at 24" Load Center pounds	Fork Length inches	Container Arrangements That May be Handled			
			44 54	54 44	44 108	54 88
Sandpiper L-42	4,000	40	X	X	X	X
ART-30	3,000	40	X	X	X	X
Telefork 62	6,000	48	X	X	X	X
Telefork 102	10,000	60	X	X	X	X

Containers of the recommended size will be compatible with all 463L materials handling equipment, since the modular arrangement of four containers will have the same base dimension, base and edge configuration, and no greater loaded weight than the 463L platform. Conventional forklift trucks will be able to handle the container at depots throughout the transportation system, since essentially all forklift trucks have at least 2000-lbs capacity at 24" load center.

COMPATIBILITY OF MARRIED MODULES WITH 463L EQUIPMENT

The Air Force 463L equipment used in MATS and the Theater Airlift is designed to handle master platforms measuring 88" x 108". Four of the proposed containers will equal one master platform in size. The 463L rail system has restraining bolts on 30" centers, and these bolts must mate with corresponding cut-outs in the container base.

The preferred solution to this problem is to join containers in pairs only, with the capability of joining them to fit either the 108"- or 88"- width rails. They can be handled in groups of four containers (i.e., two pairs) on the standard terminal handling equipment. Yet they can be separated when loading in the aircraft in order to fit the restraining bolt spacing. Figure 21 shows the arrangement of four containers when locked in the 88" rail system. For either the 108" or 88" rail spacing, a 6-inch space between each pair of containers would be necessary. If this arrangement were used in the CV-7, the overall length required for the 12 containers shown in Figure 18 would be 354". This would have no effect on the transport fit since the usable cargo space for this aircraft is 377".

USE FOR AIRDROPPABLE AND SLUNG LOADS

The container should be capable of being air dropped when rigged with adequate shock absorption material. Present Army practice for dropping pallet loads of supplies is to use an A-22 fabric container with the chute rigged on top of the load. The preferred container is too high to rig the chute on top and clear the aircraft. However, the chute can be rigged on the side of the container in a satisfactory manner. For the three aircraft considered, the additional space required by the chute would not change the transport fit in any way.

Transporting the container as a slung load from a helicopter requires that appropriate attachments must be provided for lifting. The shock and vibration requirements for this type of movement are less than others encountered in the ALOC.

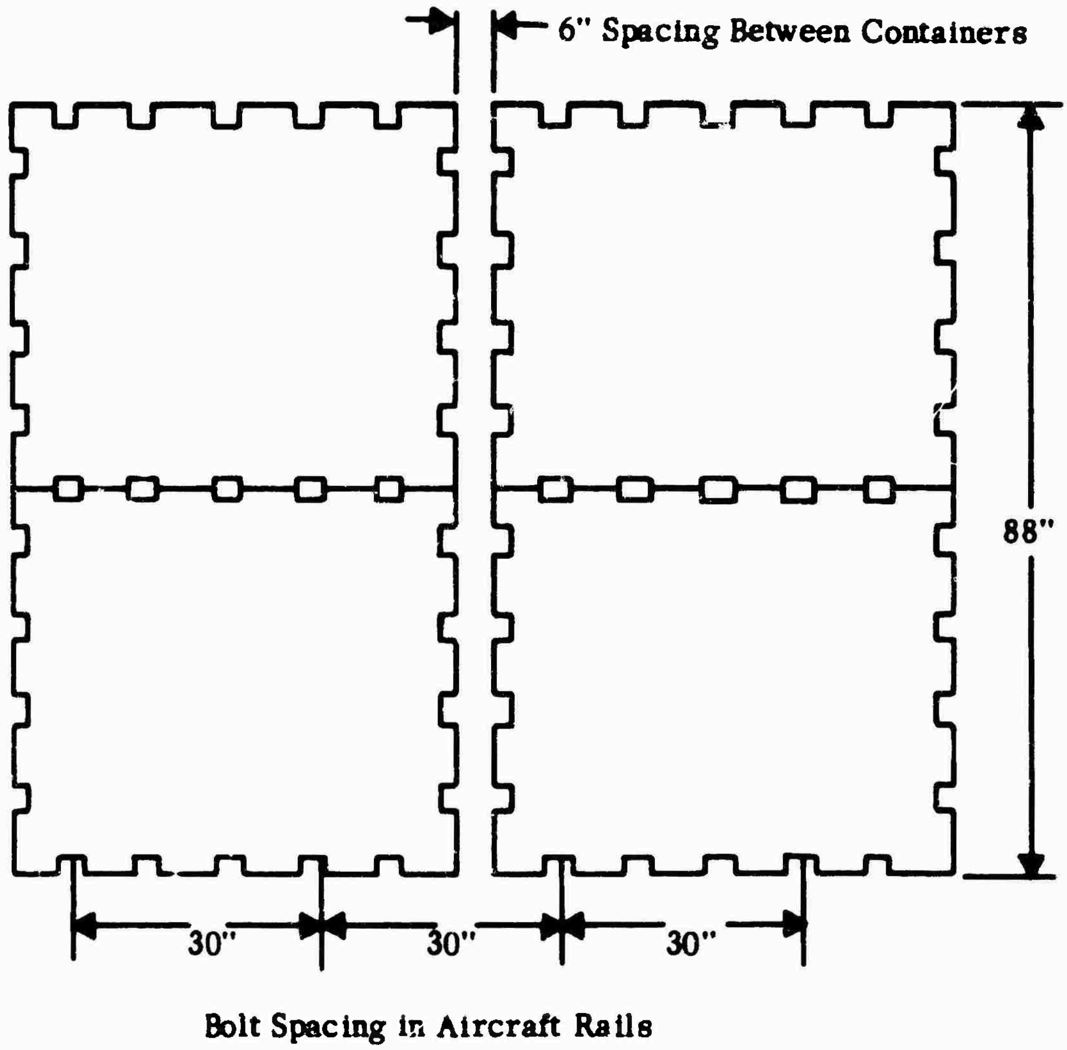


FIGURE 21 DIAGRAM SHOWING THE FIT OF CONTAINER PAIRS IN 463L EQUIPPED AIRCRAFT

ADDITIONAL FACTORS FOR EVALUATING THE CONTAINER SYSTEM

Several economic and effectiveness factors should be considered for a complete analysis of the container system. These measures are discussed in this section.

EFFECTIVENESS IMPROVEMENT IN THE ARMY RESUPPLY FUNCTION

There is no significant operational improvement for a container system in comparison to unitized pallet loads when considering such effectiveness measures as response time for support operations, aircraft restraint operations, or terminal operations. The unitized load on a standard 40" x 48" pallet will move through the ALOC with approximately the same speed and number of handling operations as the container.

The 463L materials handling support system is currently being considered for Army aircraft, and the CV-7 will be equipped with an experimental roller and rail system to accommodate the 88" x 108" master platform. If this aircraft comes into general use for transporting Army supplies with a built-in cargo handling system, an effectiveness improvement or recovery would accrue to the Army transport system. Introduction of the 463L system reduces the carrying capacity of the aircraft because of the added tare weight. The proposed container system would recover about 50% of this loss. Figure 22 shows the possible improvement expressed as a function of Army aircraft equipped to handle 463L master platforms.

A further consideration in favor of the proposed containerized transport system is that the need to return the expensive (and accountable) 463L master platforms from the battalion level would be eliminated. If Army aircraft are capable of transporting loads on master platforms, it would be logical to transfer loads directly to Army aircraft for movement to the forward area. Hence, the Army would be responsible for returning the master platforms to the Air Force. The use of expendable containers that are compatible with the 463L system would solve this problem.

EFFECTIVENESS IMPROVEMENT IN THE AIR FORCE TRANSPORT SYSTEM

Eliminating the necessity to carry the 463L platforms is not only a cost saving, but an effective increase in carrying capacity of the aircraft. In peace time the

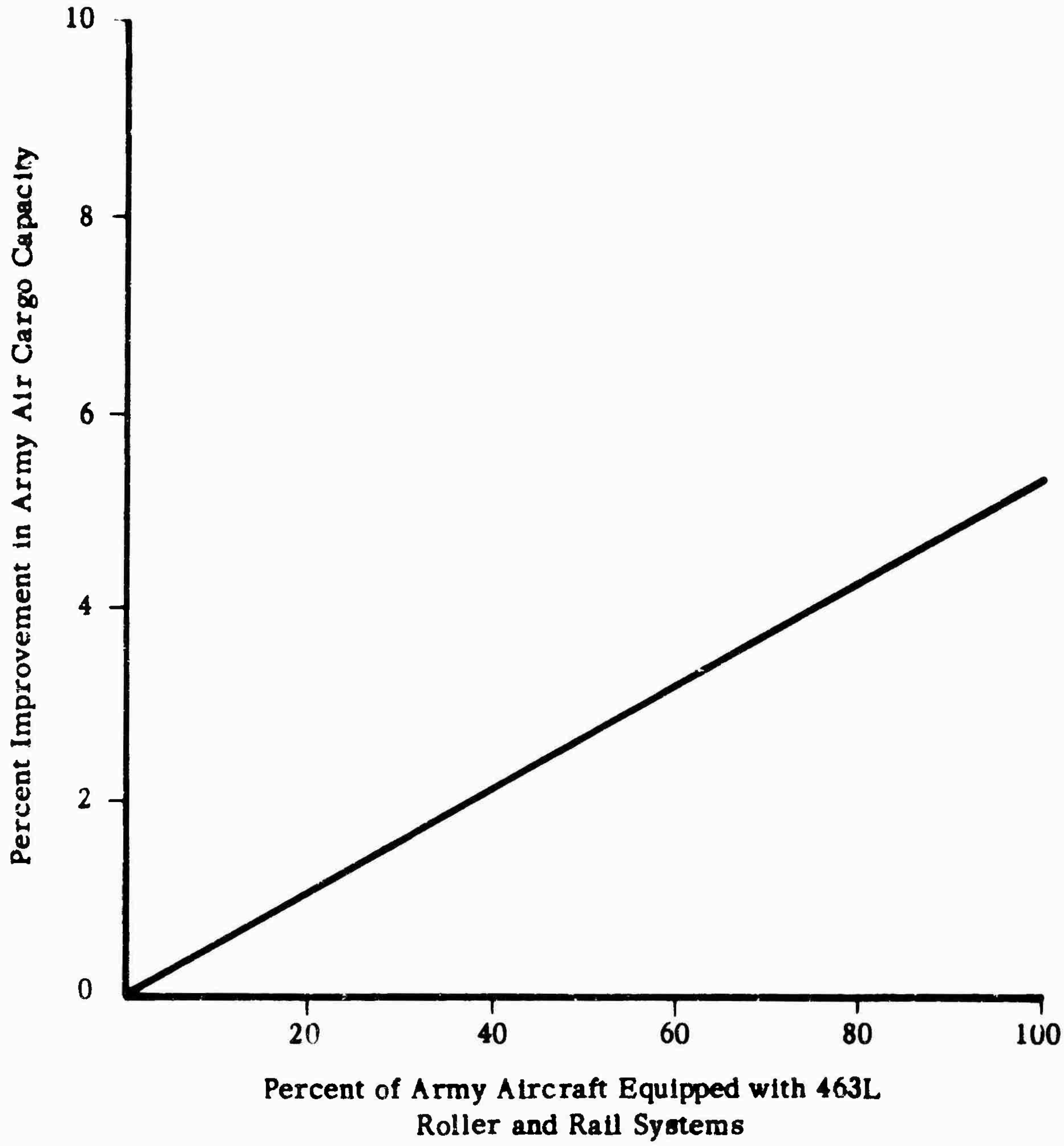


FIGURE 22 IMPROVEMENT IN ARMY AIR CARGO CAPACITY AS A FUNCTION OF 463L EQUIPPED AIRCRAFT

major emphasis is placed on cost savings. During a national emergency, the increased carrying capacity of the aircraft would assume greater importance.

If the average loaded container weight is 1600 lbs and the weight saving per container due to eliminating the 463L platform is 90 lbs, the effective increase in aircraft load carrying capacity is 5.6%. During an emergency, when large quantities of supplies would be airlifted to overseas destinations, this increase in capacity would result in an appreciable effectiveness improvement in the air logistics system.

COST SAVINGS FOR AIR RESUPPLY OF A BATTALION

A breakdown of field Army resupply indicates that between 15 and 20 lbs per man per day would fill the requirements shipped in the air transportable container [1] The number of containers required per day per battalion, plotted as a function of the percent of resupply required, is shown in Figure 23.

The range of possible savings resulting from the use of the container replacing the unitized pallet load in an ALOC is shown in Figure 24. The graphs represent 10%, 20%, and 40% of resupply requirements shipped by air. The proportion of air resupply required and the length of the ALOC are the two major factors contributing to the estimated savings. A short ALOC would be from CONUS to a European theater, while a long ALOC would be to Asia. As an example of possible savings, if 20% of resupply requirements are shipped by air from CONUS to the overseas battalion area in India (long ALOC), the estimated daily savings, based on a $50 container, would be $120 per day.

COST FACTORS FOR THE RETURN OF CONTAINERS FOR REUSE

It may be anticipated that some proportion of air transportable containers may be in such condition after use to warrant return to CONUS for reuse. In order to include peace time, limited war, and extended war possibilities, two different methods of returning the container through the ALOC may be considered. These are:

1. Return of container from battalion area (in collapsed condition) to field Army rear by Army aircraft or trucks.

1 Determination of Requirements for Unitization of Cargo Project CD 58-7, January 1960, U.S. Army Transportation Combat Developments Group, Fort Eustis, Virginia.

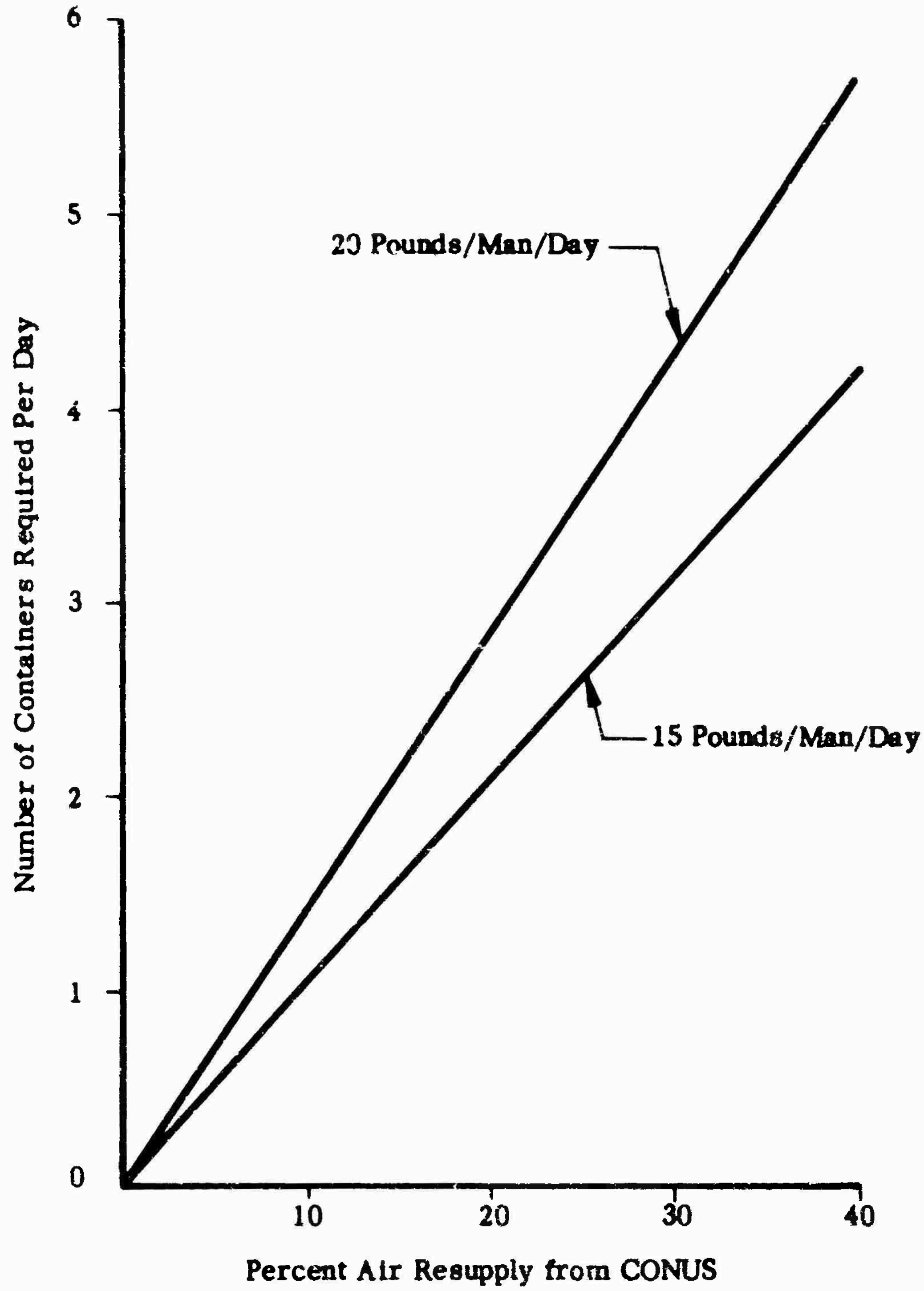


FIGURE 23 CONTAINER REQUIREMENTS PER DAY PER BATTALION FOR AIR RESUPPLY

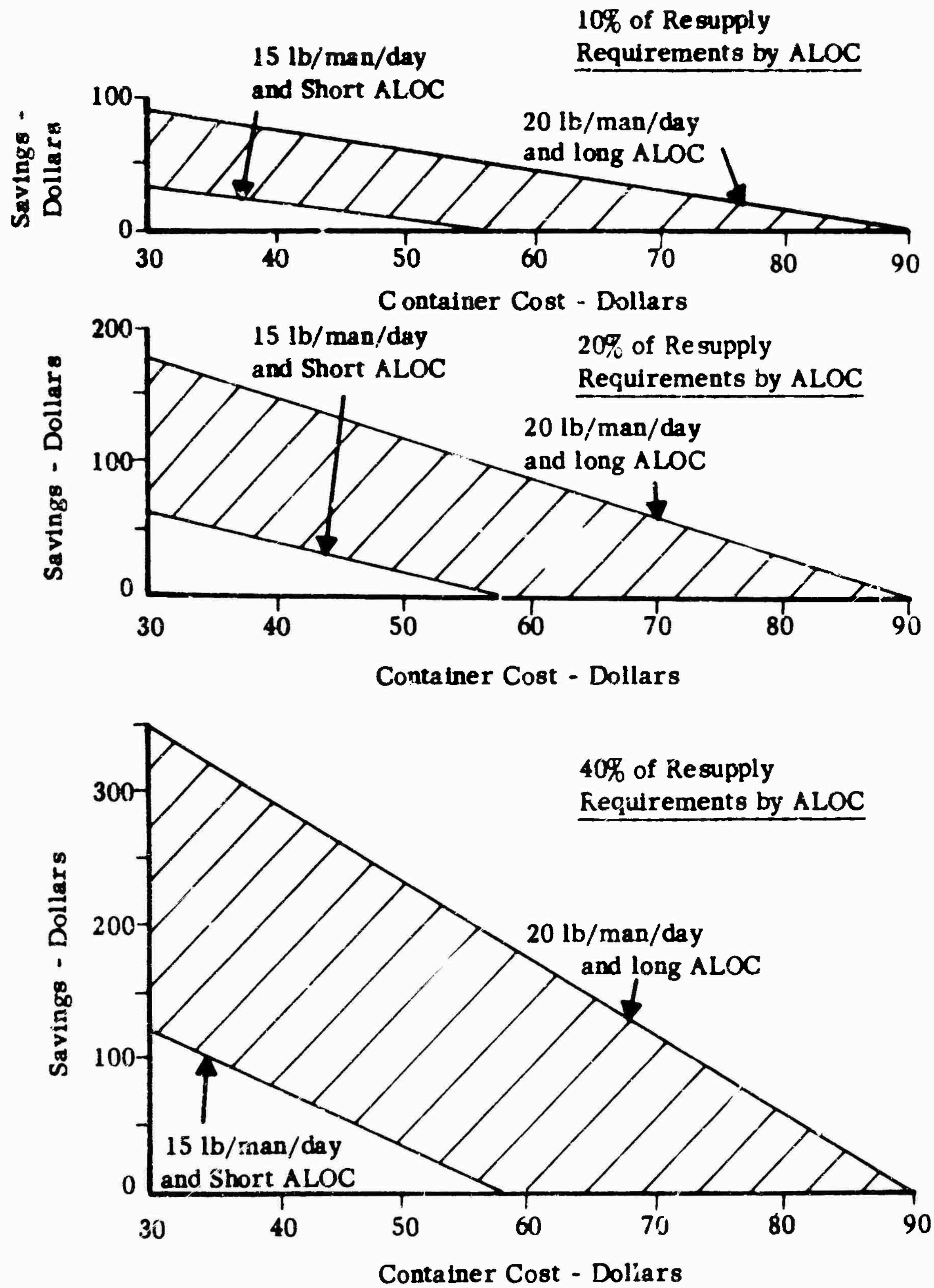


FIGURE 24 RANGE OF POSSIBLE SAVINGS PER DAY PER BATTALION FOR AIR RESUPPLY

Return by theater airlift from field Army rear base to MATS APOE.

Return by MATS aircraft to MATS APOD on the coast of the CONUS.

2. The same procedure except return from MATS APOE to port of embarkation by military surface transportation and return to CONUS by ship.

These two possible return routes, essentially "air" or "ship", give rise to four possible ways to consider the return costs, based on the four following situations.

1. Returning MATS capacity being critical, and return of containers considered an additional airfreight expense ultimately borne by the Department of Defense.

2. Returning MATS capacity not critical, with sufficient unallocated cargo space to consider the MATS leg of return of containers through the ALOC as incurring no actual additional cost to the Department of Defense.

3. In like manner, considering return MSTS or contract surface ship space is limited, thus adding usual ocean transportation rates to ship return of containers to CONUS.

4. Sea return of containers in otherwise unoccupied cargo space, incurring no additional cost for the ocean leg of a return trip.

The cost of returning the container for reuse for the above four situations has been estimated as shown in Table 17.

TABLE 17

ESTIMATED COST TO RETURN CONTAINERS TO CONUS FOR REUSE*

No.	Description	Estimated Cost
1	MATS airlift, charge rate	$53.10
2	MATS airlift, no charge	3.30
3	MSTS marine transportation, charge rate	11.60
4	MSTS marine transportation, no charge	3.60

* The following assumptions apply: Return from European theater over ALOC distances identical to those used in Appendix III. Ocean rates based on MSTS charges, depot handling charges based on commercial figures and SUNSPOT depot cost questionnaire responses. Surface rates in the U.S. based on commercial truck and rail rates. Theater return transportation costs not charged.

The effect of returning the containers for subsequent reuse on the cost savings of the container system is shown by Table 17 to be dependent on the cost of return. If MATS transport charges must be assigned to the return leg, it is clear that air return is not economically feasible for a container with a purchase cost in the $50.00 range.

Return by sea, a cheaper method if intercontinental transportation charges are assigned, has the disadvantage of requiring a considerably greater number of containers in the "cycle", due to the 12 to 25 days required for the ocean leg.

If, on the other hand, return airspace may be considered essentially "free", air return of containers may well lower the overall container system cost. The degree of cost improvement cannot reasonably be postulated, since it will be a direct function of the proportion of containers that are returnable and the number of round trips the average container will withstand.

No cost reduction due to return and reuse of containers has been applied to the justifiable container cost. The following example will serve to illustrate the possible advantage due to return and reuse, however. If 25% of the containers are returned for a second trip and if the MATS airlift charges are not imposed, the justifiable container cost would be increased by $14.00. Considered from another viewpoint, the effective container cost would be reduced by $7.00; i.e., $43.00 for a container costing $50.00.

REDUCTION IN CARGO DAMAGE, LOSS, AND PILFERAGE RESULTING FROM CONTAINERIZATION

For commercial shippers, containerization has resulted in a reduction of cargo damage, loss, and pilferage. Reliable and complete data on the percentage reduction do not exist. From the available information it can be inferred that a saving of about $2.50 per ton can be expected when commercial shipments are containerized.

The military ALOC is not directly comparable to commercial operations because the military system is under somewhat better control and surveillance. Although it appears that some savings would accrue to the Army in the form of reduced damage, loss, and pilferage, this has been neglected in estimating the advantages of the containerized system.

FORCE ANALYSIS OF THE CONTAINER

In the design of a pinned structure, a force analysis is necessary in order to perform a stress analysis of individual components. This force analysis is based on expected conditions of ground handling and transportation for the container as a single unit, a double unit, and four- and eight-container configurations. Although the 35"-high container has been eliminated as a possible container size, this analysis considers forces on containers when they are stacked two high.

The analysis is general in approach. It will yield information regarding size and strength requirements for individual container members only when it is applied to a specific design concept. However, some assumptions must be made as to the probable construction of the container in order to accomplish a realistic force analysis.

The container is conceived to be a closed truss-like structure whose load-carrying members are simple-shaped members and whose six sides serve only to contain the packed cargo and transfer the loadings to the truss. Such a structure is shown in Figure 25 and becomes the basis for the force analysis. Also shown is a four-container configuration with the locations (small squares) of the inter-box attachments. These attachments of the container can sustain tension and shear but are not needed for compressive forces. Considering cost, weight, and reliability, the container should be designed for stress rather than for buckling resistance.

The following assumptions are made:

1. The plate (or wall) material is capable of transmitting the internal inertial loads to the truss-like framework and still remaining intact.

2. The plate material, due to its low buckling strength (hence, low cost) does not contribute to the basic strength of the load carrying members (horizontals, verticals, and diagonals).

3. Tension forces are allowed in all members.

4 Compression and bending loads are allowed in horizontal and vertical members only.

5. No compression loads are allowed in the diagonals.

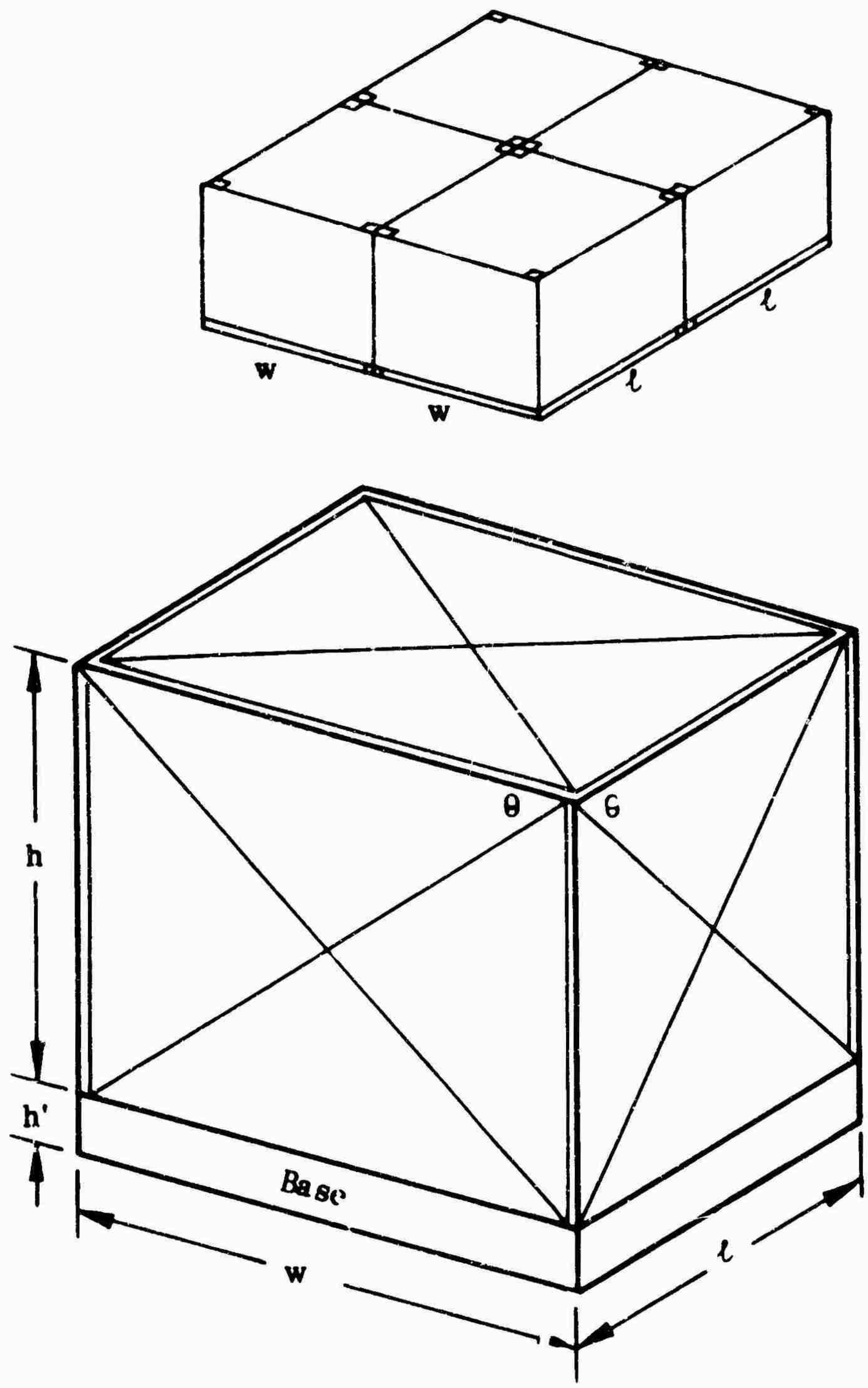


FIGURE 25 BASIC CONTAINER STRUCTURE AND FOUR-CONTAINER CONFIGURATION

6. There is no bending resistance allowed at any joint. This is not a conservative assumption. Secondary stresses developed in the members are usually of the order of 10% of the direct stress.

7. All inertial loads are uniformly distributed over the side of the container in question. This assumption is necessary because the configuration of the contained cargo is unknown.

8. The bottom face of the container is uniformly supported. This assumption applies when a four-container configuration is supported by the floor mounted rollers within 463L equipped aircraft.

ANALYSIS

Forklift Handling

Single containers which are handled by forklift will not produce the highest member loads. Containers attached in pairs do, however, create high member loads as shown in Figure 26 (appropriate "g" loadings are denoted as Wg where W represents the weight of contained cargo and is assumed to be geometrically centered in the container). The appropriately loaded members are shown in solid lines while the relatively unloaded members are shown dashed. The g loading can arise from bumps as the forklift travels over uneven ground.

The force per attachment is

$$F = \frac{1}{2h} Wg\left(\frac{w-d}{2}\right) \text{tension.}$$

The diagonal tensile load is

$$F_1 = \frac{F}{\cos\theta}.$$

The upright compressive load is

$$F_2 = F \tan\theta = F \frac{h}{w}.$$

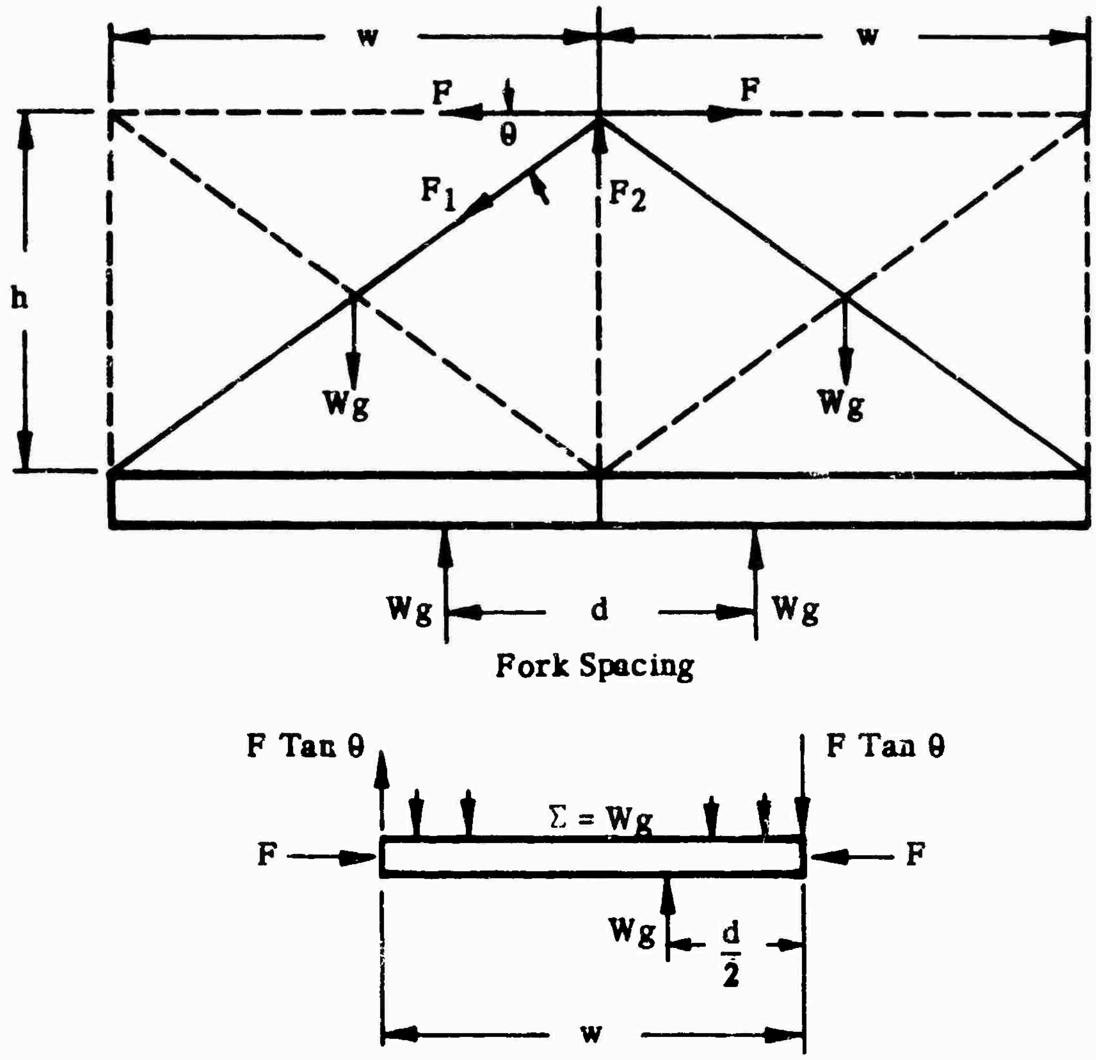


FIGURE 26 FORCE DIAGRAM FOR TWO-CONTAINER CONFIGURATION WHEN HANDLED BY FORKLIFT TRUCK

Although Figure 27 represents another possible loading, no g forces are involved since travel is not possible--only relocation of the containers by means of fork-lift at one end.

The compressive force in upper attachment is

$$F = \frac{1}{4} W \frac{w}{h} .$$

The upright compressive load is

$$F_1 = \frac{1}{4} W .$$

Each diagonal tensile load is

$$F_2 = \frac{F}{\cos\theta} + \frac{F_1}{\sin\theta} .$$

The force per lower attachment is

$$F_3 = \frac{1}{4} W \frac{w}{h} \text{ tension.}$$

The loads in middle uprights are indeterminate.

Vertical Acceleration

Single Layer

For downward acceleration, the bottom face of the container is loaded in a simple direct compression with a distributed load, Wg. Due to the support of the aircraft cargo deck, this is probably an insignificant loading configuration.

Upward acceleration will load the top of the container as a plate with distributed load Wg whose reaction will put the horizontals in bending and the uprights in direct tension. The uprights will be loaded with 1/4 Wg and the horizontals will have a distributed load 1/4 Wg with end reactions equal to 1/8 Wg.

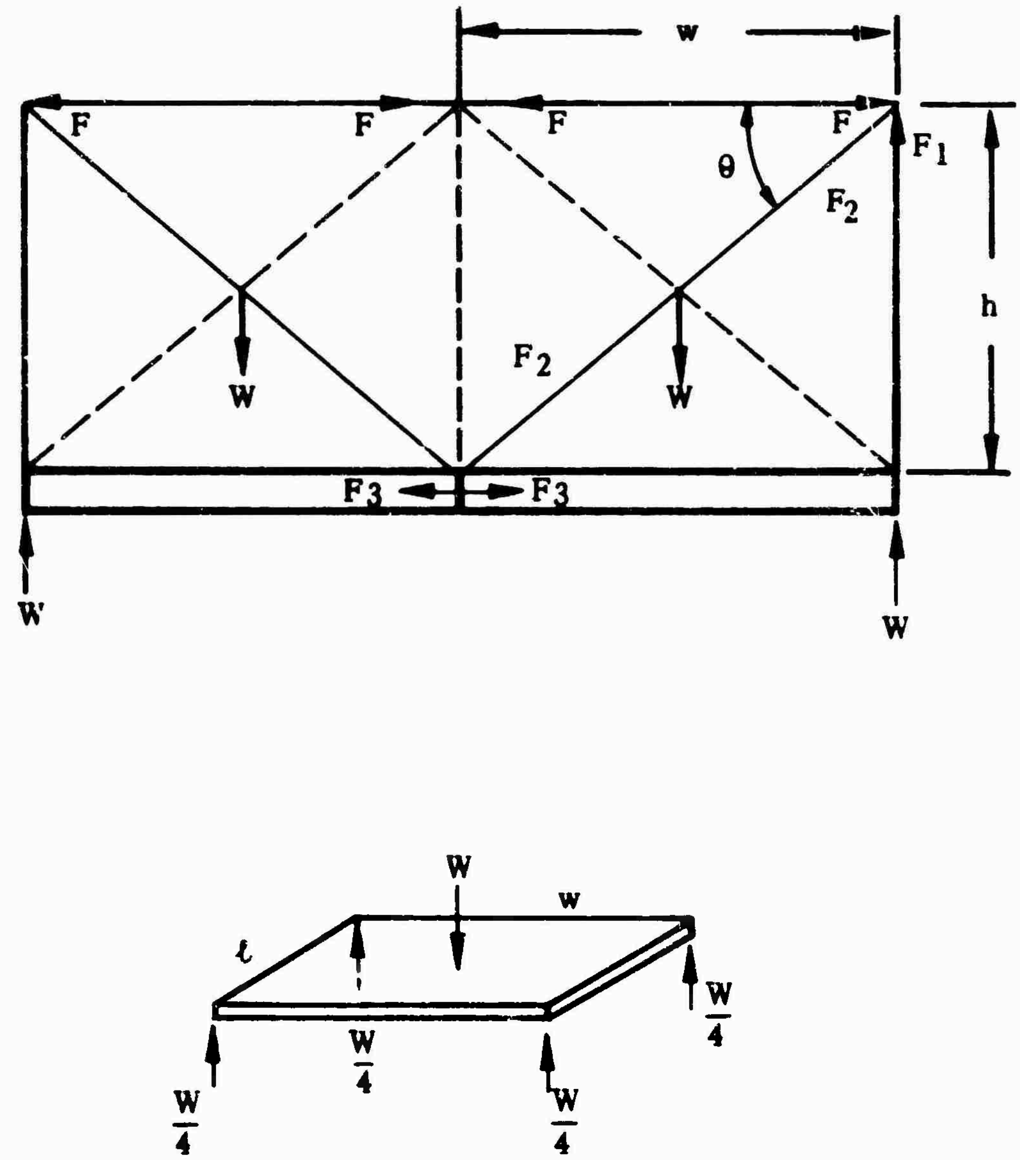


FIGURE 27 FORCE DIAGRAM FOR TWO-CONTAINER CONFIGURATION WHEN LIFTED AT THE ENDS

Naturally the attachments to the aircraft must also sustain these upward loads.

Double Layer

During vertical acceleration downward, as shown in Figure 28, the containers, stacked two high, produce simple compression and the uprights assume all of the load. The diagonals insure stability.

The compressive force in each bottom upright is

$$F = \frac{1}{4} Wg$$

and buckling must be investigated.

During vertical acceleration upward, the bottom uprights are loaded in tension due to both containers and

$$F = \frac{1}{2} Wg \text{ tension.}$$

Similarly, the tops of the containers are loaded as a plate and the four upper horizontals are loaded as beams with distributed load 1/4 Wg and end reactions 1/8 Wg downward.

Forward Acceleration

Single Layer

Figure 29 illustrates forward acceleration, and even though four containers are attached they are considered to act as independent pairs. The analysis of all four acting together would require a knowledge of, and consideration for, the deflections of the various members. The forward and rear pairs are assumed to act independently.

The aircraft deck restraint on each rear corner is:

Horizontally,

$$F_H = Wg;$$

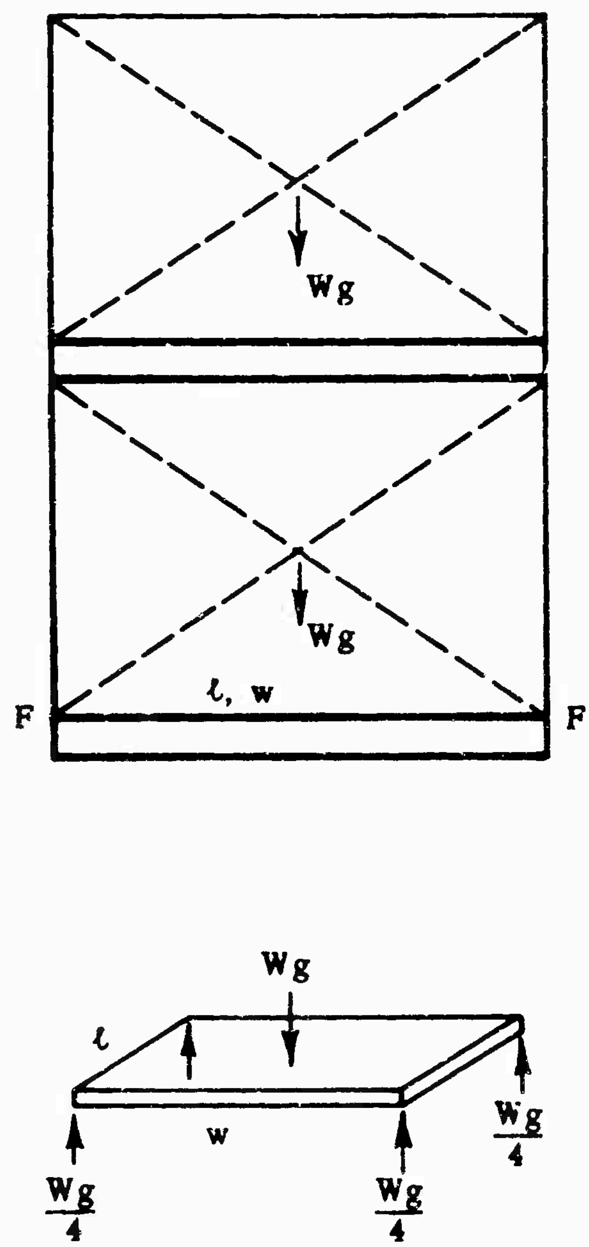


FIGURE 28 FORCE DIAGRAM FOR VERTICAL ACCELERATION WHEN CONTAINERS ARE STACKED TWO HIGH

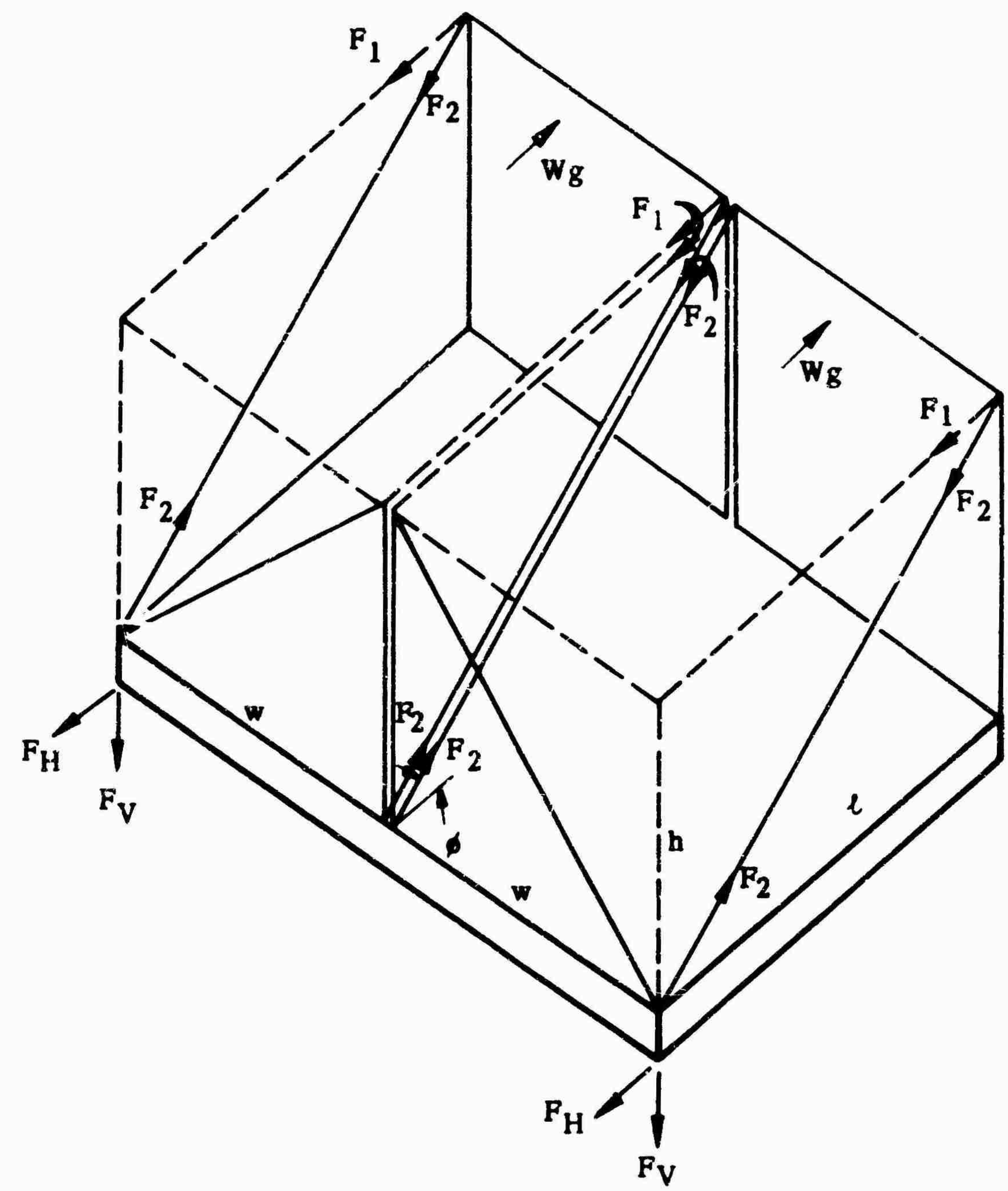


FIGURE 29 FORCE DIAGRAM FOR FORWARD ACCELERATION FOR TWO-CONTAINER CONFIGURATION

Vertically.

$$F_V = \frac{1}{2} Wg \frac{h}{\ell};$$

Diagonal tension,

$$F_2 = \frac{F_1}{\cos\phi} = \frac{1}{4} \frac{Wg}{\cos\phi}.$$

The two central diagonals give rise to forces F_3 as shown in Figure 30 in the plane of the rear diagonals as a compressive force in the uprights.

Compression in central rear uprights

$$F_3 = \frac{1}{4} Wg \tan\phi$$

$$= \frac{1}{4} Wg \frac{h}{\ell}.$$

Consequently, the tensile load in the rear diagonals

$$F_4 = \frac{F_3}{\sin\theta} = \frac{1}{4} \frac{Wg}{\sin\theta} \frac{h}{\ell}.$$

The load in the attachment

$$F_5 = F_4 \cos\theta = \frac{1}{4} Wg \frac{w}{\ell}.$$

On the forward face of the containers we have the forces Wg/4 shown in Figure 30.

Therefore, the uprights and horizontals are loaded in bending with a distributed load Wg/4 and supported by end reactions Wg/8.

There is an additional force, F_6, due to the diagonal tension, F_2, acting in compression on the uprights.

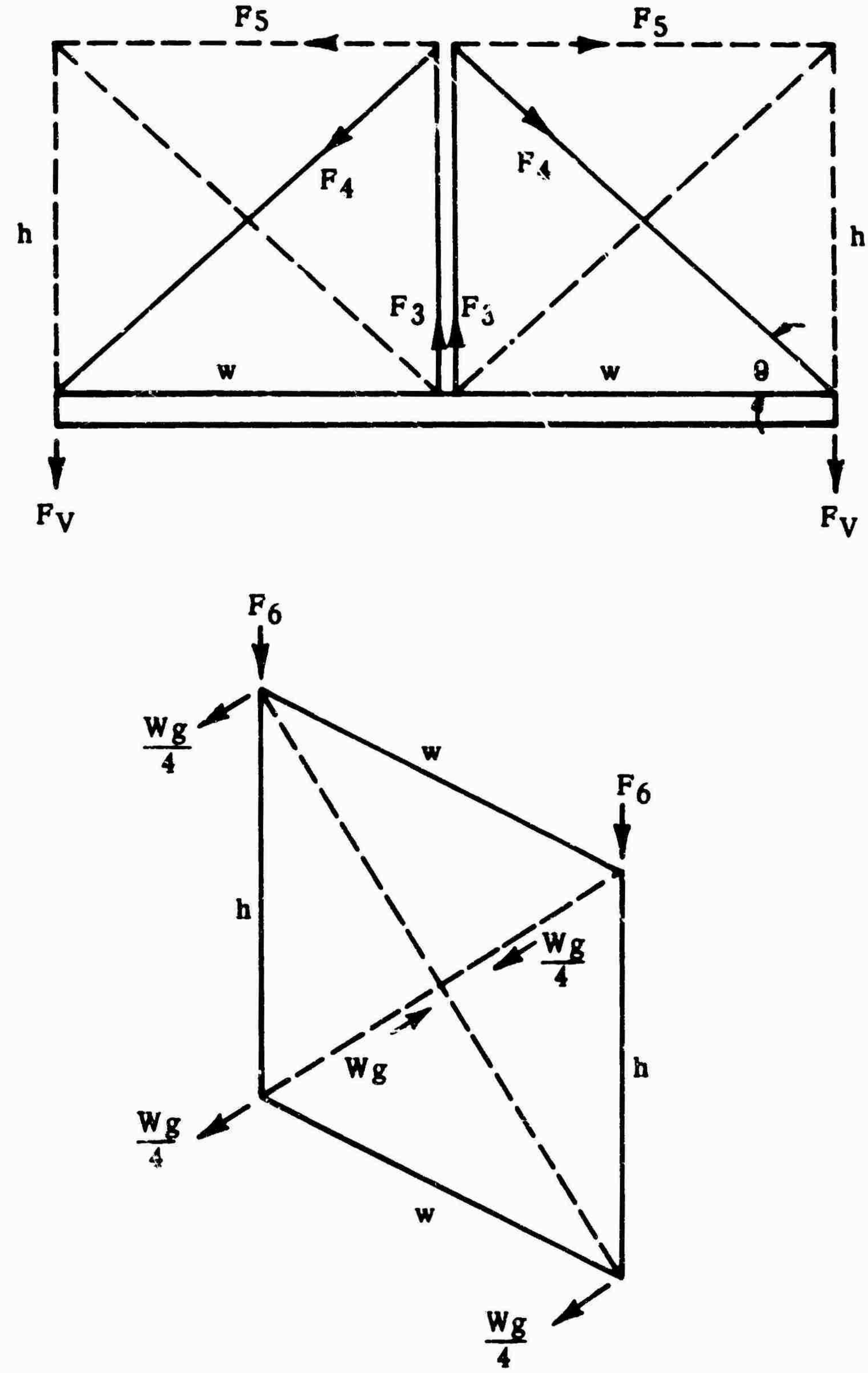


FIGURE 30 FORCES IN REAR STRUCTURAL MEMBERS AND FORWARD FACE LOADING RESULTING FROM FORWARD ACCELERATION

$$F_6 = F_2 \sin\phi = \frac{1}{4} Wg \tan\phi$$

$$= \frac{1}{4} Wg \frac{h}{\ell} .$$

Hence, buckling of these uprights must be investigated.

Double Layer

Consider a two-high stack of containers as shown in Figures 31 and 32. Again assume the forward and rear pairs to be independent.

The aircraft deck restraint at each rear corner with the same assumption as before,

$$F_V = 2 Wg \frac{h}{\ell}$$

$$F_H = 2 Wg.$$

Each diagonal is loaded, initially due to the reaction against Wg within the individual containers

$$F_2 = \frac{1}{4} \frac{Wg}{\cos\phi} ,$$

but the lower left diagonal (as viewed in Figure 31) must also sustain the additional tension due to the container above

$$F_3 = \text{Diagonal component of } \frac{Wg}{2} + F_2 = \frac{1}{4} \frac{Wg}{\cos\phi} + \frac{1}{2} \frac{Wg}{\cos\phi} .$$

The upper four containers are loaded as in the previous analysis.

Of interest now is how these upper four containers further load the uprights and diagonals of the members of the lower four containers.

The rear vertical plane of members is an indeterminant structure with redundant members. The bar forces cannot be determined, but a conservative

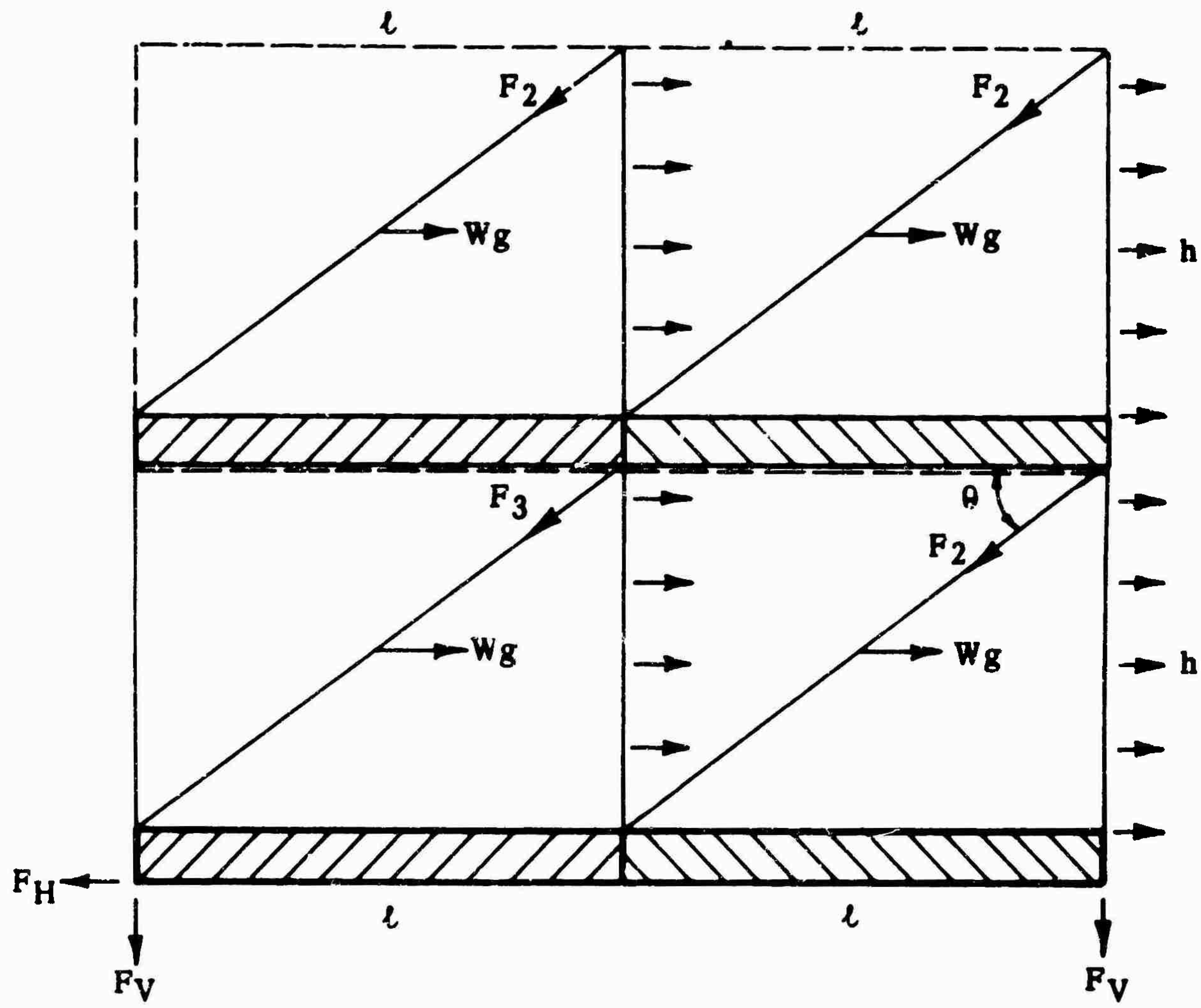


FIGURE 31 DIAGRAM SHOWING DIAGONAL LOADING FROM FORWARD ACCELERATION WHEN CONTAINERS ARE STACKED TWO HIGH

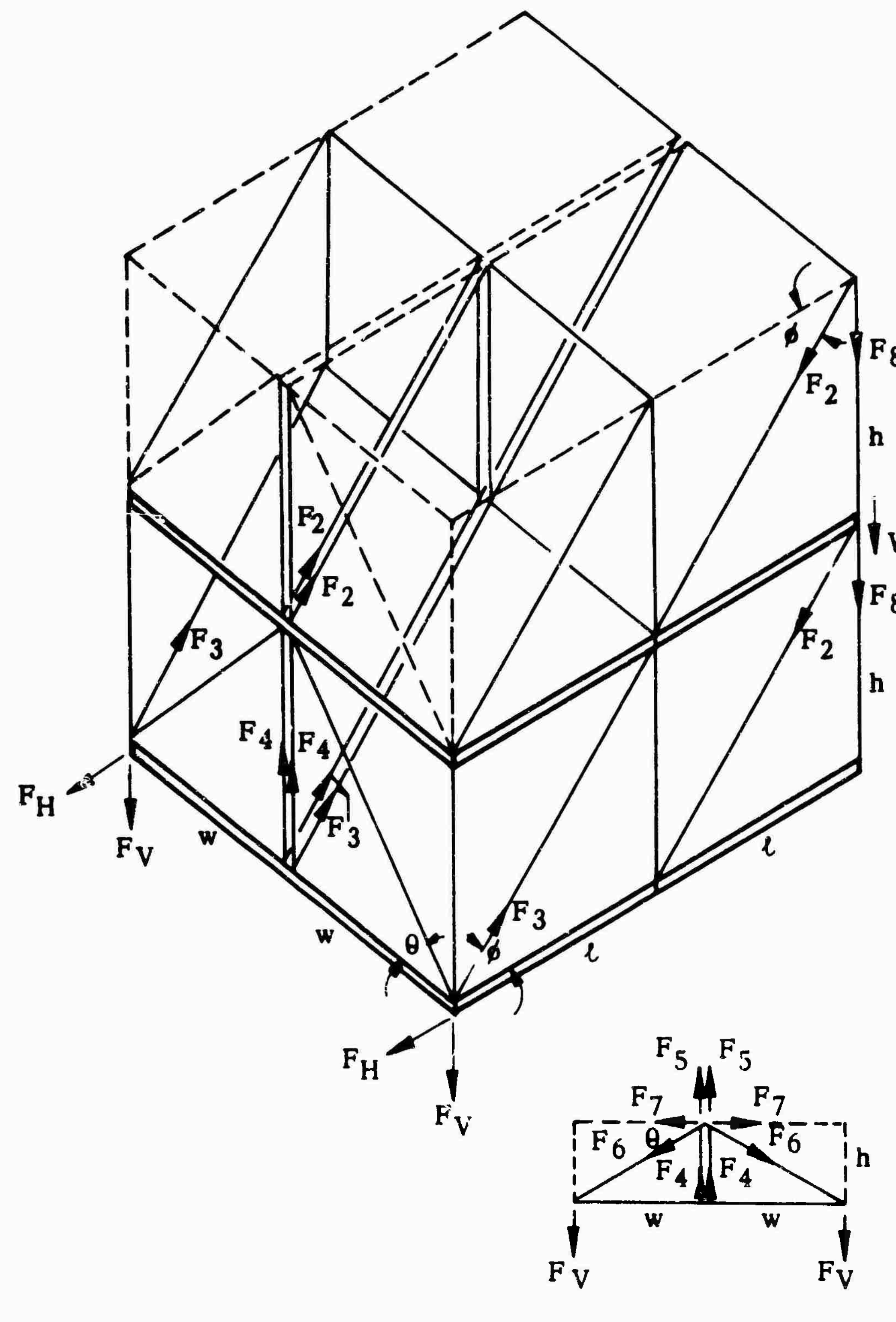


FIGURE 32 FORCES RESULTING FROM FORWARD ACCELERATION IN AN EIGHT-CONTAINER CONFIGURATION

approach to an approximate solution can be made. This approach assumes that the forces in the two central, upper, rear diagonals transfer their entire load (respective of component) to the lower uprights and diagonals immediately below. The consequence of this assumption is to calculate a greater than true load on the lower members and eliminates any load in the upper members.

Since a container design would be based upon this higher than true load, the design would be adequate for any location of the container in the group of 8.

Referring again to the inset of Figure 32,

$$F_4 = F_3 \sin\phi$$

$$= \frac{1}{2} Wg \frac{h}{\ell}$$

$$F_5 = F_2 \sin\phi$$

$$= \frac{1}{4} Wg \frac{h}{\ell} .$$

Therefore, the compressive load in each of the central uprights

$$F_4 - F_5 = \frac{1}{4} Wg \frac{h}{\ell} .$$

Now the tension in the diagonals

$$F_6 = \frac{F_4 + F_5}{\sin\theta} = \frac{3}{4} \frac{Wg}{\sin\theta} \frac{h}{\ell} .$$

The horizontal component is the loading on the attachment

$$F_7 = F_6 \cos\theta$$

$$= \frac{3}{4} \frac{Wg}{\tan\theta} \frac{h}{\ell}$$

$$= \frac{3}{4} Wg \frac{w}{\ell} .$$

Referring to Figure 32, the forward upright is in compression from three individual sources of load:

First, due to the component of F_2

$$\text{a. } F_8 = F_2 \sin\phi = \frac{1}{4} Wg \frac{h}{\ell}$$

Second, due to the dead weight of the container above

b. W

Third, due to the reaction of the upper container (or the vertical component of the diagonal force F_2 in the upper container)

$$\text{c. } F_8 = \frac{1}{4} Wg \frac{h}{\ell}$$

Therefore, the total load in the forward bottom upright is the sum

$$F_9 = \frac{1}{2} Wg \frac{h}{\ell} + W = W\left(\frac{gh}{2\ell} + 1\right).$$

Since this upright supports a distributed load of 1/4 Wg, buckling will be the most serious consideration here.

Lateral Acceleration

This direction of loading, even with the interchanging of dimensions w and ℓ, will produce lower bar forces due to the lower g levels.

From the standpoint of cost it is assumed, naturally, that all diagonals will be made of the same cross section of material and all other members will be identical to accommodate any container orientation within the aircraft.

VIBRATION, SHOCK, AND STATIC LOADING CRITERIA

VIBRATION

The combined vibration spectra, taken from TB55-100, has been replotted in Figure 33 for highway, rail, and air transportation. Marine transportation has been excluded from this study. In order to arrive at a realistic criteria for vibration, other references have been consulted. In particular, the Shock and Vibration Handbook, edited by Harris and Crede[1], extracts test data from numerous Government publications. This data also has been plotted in Figure 33 for comparison. The specific page references are given on the curves.

The disagreement between the two sources of data cannot be resolved readily but it is suggested that a sinusoidal vibration test of 5 g's in three directions from 1 to 1000 cps at a 1-octave/minute sweep rate be the criteria. No provision should be made for dwelling at any natural frequency.

As to the time of test, the longest duration of 150 hours is obtained from highway operation of 5000 miles at an average speed of about 35 mph. Since fatigue life is the important factor in this kind of vibration test, no reduction of testing time should be allowed.

Because a fully loaded container tested at 5 g's requires the use of a large and expensive vibration table, it is more likely that only those critical parts (clips, volts, attachments, etc.) of the containers loaded in a suitable jig will be tested in vibration.

SHOCK

The shock spectra of TB55-100 is summarized in Figure 34 and, with the exception of curves A and B for rail, seems to be in good agreement with various other published data. It is suggested, then, that a 12-g shock of duration 0.080 to 0.100 second should be the design criteria.

Although shock and high g loadings (and vibration in some cases) can be determined analytically, many problems exist in transforming analytical results to real environments. Therefore, proof tests are the final confirmation of the design. Such proof tests are usually the drop tests.

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1 Shock and Vibration Handbook, C.M. Harris and C.E. Crede, Volume 3, McGraw-Hill Book Company, Inc., 1961.

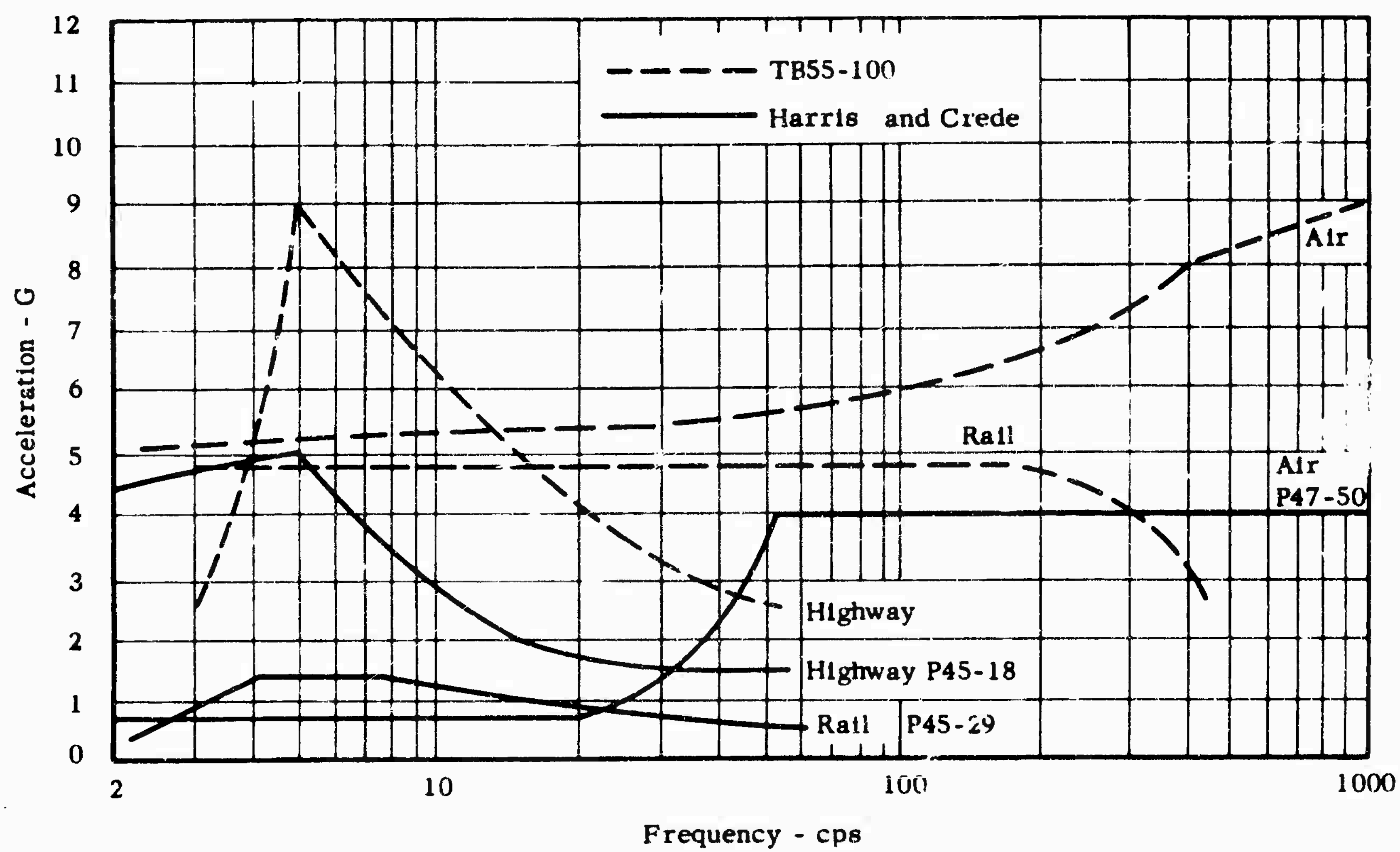


FIGURE 33 VIBRATION SPECTRA FROM TB55-100 AND HARRIS AND CREDE

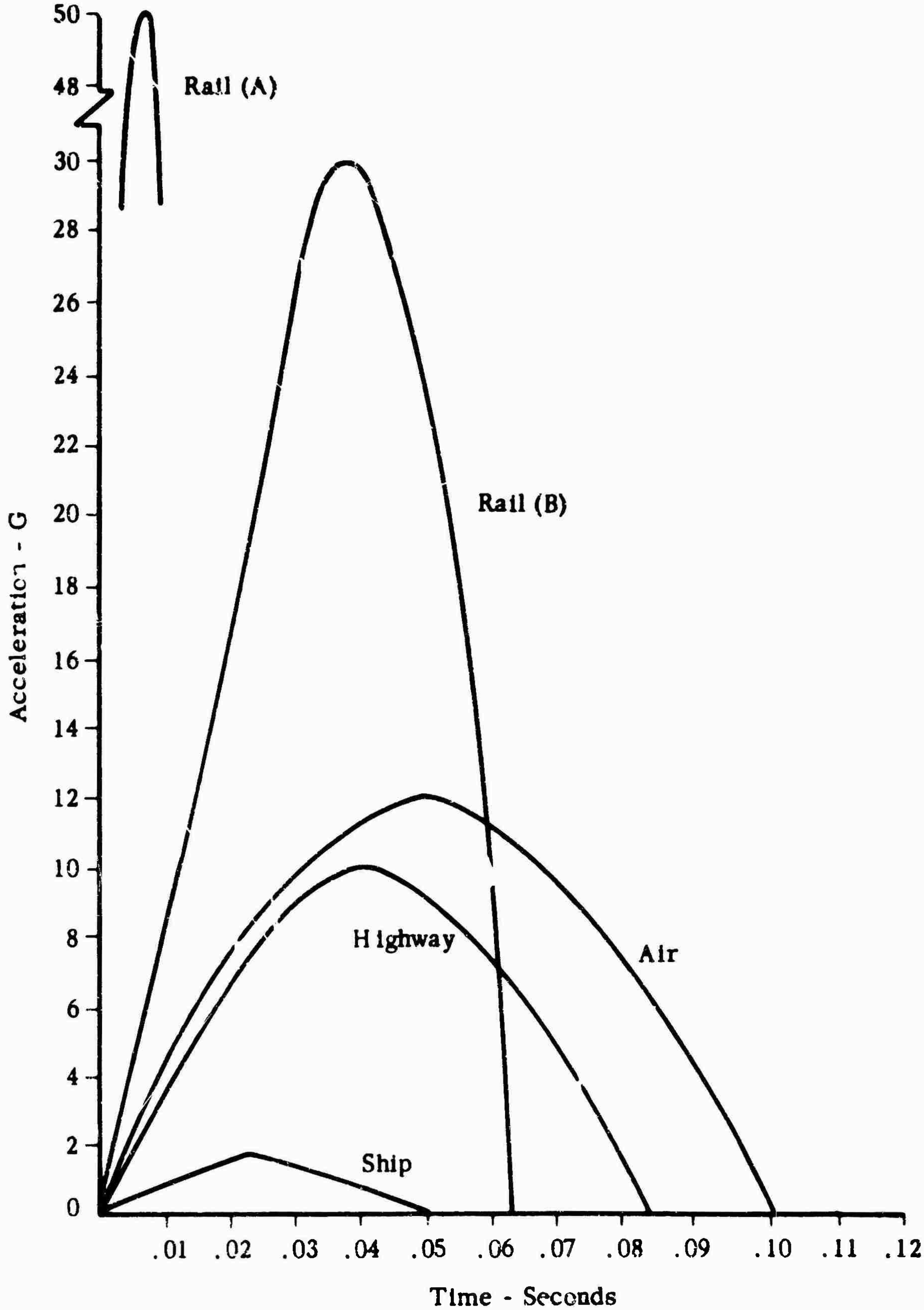


FIGURE 34 TB55-100 SHOCK SPECTRA

With particular reference to MIL-STD-810, Table 516-I, drop heights of 24 inches should lead to an acceleration loading of about 100 g (this is determined from Figure 41-1 of Harris and Crede). These drop tests are believed to be applicable only to an investigation of the integrity of the shock protected equipment when accidentally dropped, but not to the specific design requirements for a shipping container when loaded aboard aircraft. As such, an analysis of the container for cargo aircraft use might represent a minimum structural design while the drop test will confirm the gross survivability of the container alone. For this aircraft acceleration loading, MIL-STD-810, Method 513, Table 513-I, should be used.

CONTAINER DESIGN

In the foregoing sections of this report the design requirements for the air transportable container have been developed. For convenience, six basic requirements are restated here.

1. Outside dimensions = 44" x 54" x 70" high (approximately)

2. Allowable weight = 195 pounds

3. Justifiable cost = $58.00

4. Protect cargo equivalent to level A packing

5. Two containers suitably joined together should fit the 463L aircraft rail system, 108" or 88" wide

6. Withstand shock and vibration resulting from handling and transportation

It has been shown that approximately 63% of the justifiable cost results from elimination of the master platform and attendant handling savings by the Air Force. Including this saving, the purchase price of the container must be approximately $.30 per pound. If the requirement for fitting the 463L aircraft rail system were not included, the justifiable cost would be $24.00, making the price about $.12 per pound. On the other hand, elimination of the master platform and restraining net means that all vibration and shock forces must be absorbed by the container itself, and this increases the forces that the container must withstand. In this analysis, only the major design considerations have been given detailed study.

CONTROLLING DESIGN STRENGTH FACTORS

Various design criteria are applicable to this container. The purpose of the following investigation is to determine the worst or prevailing criteria on which to base the size of container components.

Vibration

It is difficult to determine how to apply a vibration environment to this container design in an explicit manner. The usual application of such environment involves investigation of natural frequencies of components, insuring that these frequencies are not within certain critical excitation bands, and providing suitable damping where necessary to reduce peak deflections and stresses. At worst, if stresses are high, designing for a suitable fatigue life becomes important. A container, however, exhibits little flexibility and is a massive structure when loaded. Hence, the usual application of vibration criteria is not important. Some attention must be given to this environment, but it is more for the purpose of avoiding stress concentrations of welded joints, threaded connections subject to loosening, and other finer details which are properly the subject of a final rather than a conceptual design.

Shock

The shock criteria presented in TB-55-100 and MIL-STD-810A (USAF) are useful guides for designing equipment that must be protected against such shock inputs. Application of this criteria in the conceptual design stage is not well defined. TB-55-100 specifies the maximum allowable stresses for a shock load and time pulse "in the restraining system". However, this requirement is not presented under continuous load and with the load factor conventionally used in aircraft design. For the present purpose of analysis, the requirements under the following section, Structural, are assumed to be controlling. However, upon construction of a prototype container, a review of the TB-55-100 and MIL-STD-810A (USAF) (drop test) requirements should be made as proof of operational capabilities.

Structural

The applicable structural loading requirements for the container design have been based on cargo aircraft loadings. These are listed in MIL-STD-810A, Table 513-I, "Structural Test", as well as in military specifications for aircraft strength such as MIL-A-8865 (ASG) and Civil Air Manual, Section 4. Under the above specification, the 9.0 g forward structural loading is most frequently referenced and is found to be the most severe design criterion which becomes the design basis for the container components.

However, this load factor originated with emergency or crash landing conditions, as clearly stated in MIL-A-8865, and in this case is referenced as an ultimate load factor of 8 g. In the Civil Air Manual, an ultimate load factor of 9 g is referenced with the comment "...... it is expected that parts of the airplane may be damaged." It is the intent of these specifications to avoid a structure which would permit serious injury to occupants, and particularly to the crew of cargo aircraft. In view of this interpretation, the ultimate stress of the material is used in the design which, therefore, would permit yielding and possible permanent damage. However, the design would not result in rupture under these loading conditions to allow the container contents to endanger the aircraft occupants. This interpretation is at variance with TB-55-100, but it is also based upon a load for a greater time duration. This interpretation is considered consistent with the aircraft design and necessary to meet the restraints of this study with a successful container.

FORCES ON CONTAINER RESULTING FROM 9 g LOAD FACTOR

Containers can be combined in two different ways to fit the 108" and 88" aircraft rail systems. The two arrangements are shown in Figure 35. The values of ℓ and w as related to the force diagrams in Figures 29 and 30 are shown.

The values for the forces developed in the various structural members of two joined containers for a 9 g load are shown in Table 18. The formulas for these forces were developed in the force analysis section.

TABLE 18

FORCES IN STRUCTURAL MEMBERS OF TWO JOINED CONTAINERS FOR 9 g LOADING

Force	Formula	88" Rail Spacing (lbs)	108" Rail Spacing (lbs)
F_v	$Wg\ h/2\ell$	11,030	13,500
F_2	$Wg/4\cos\phi$	7,120	8,120
F_3	$Wg\ h/4\ell$	5,500	6,750
F_4	$Wg\ h/4\ell \sin\theta$	6,600	8,700
F_5	$Wg\ w/4\ell$	3,660	5,520
F_6	$Wg\ h/4\ell$	5,500	6,750

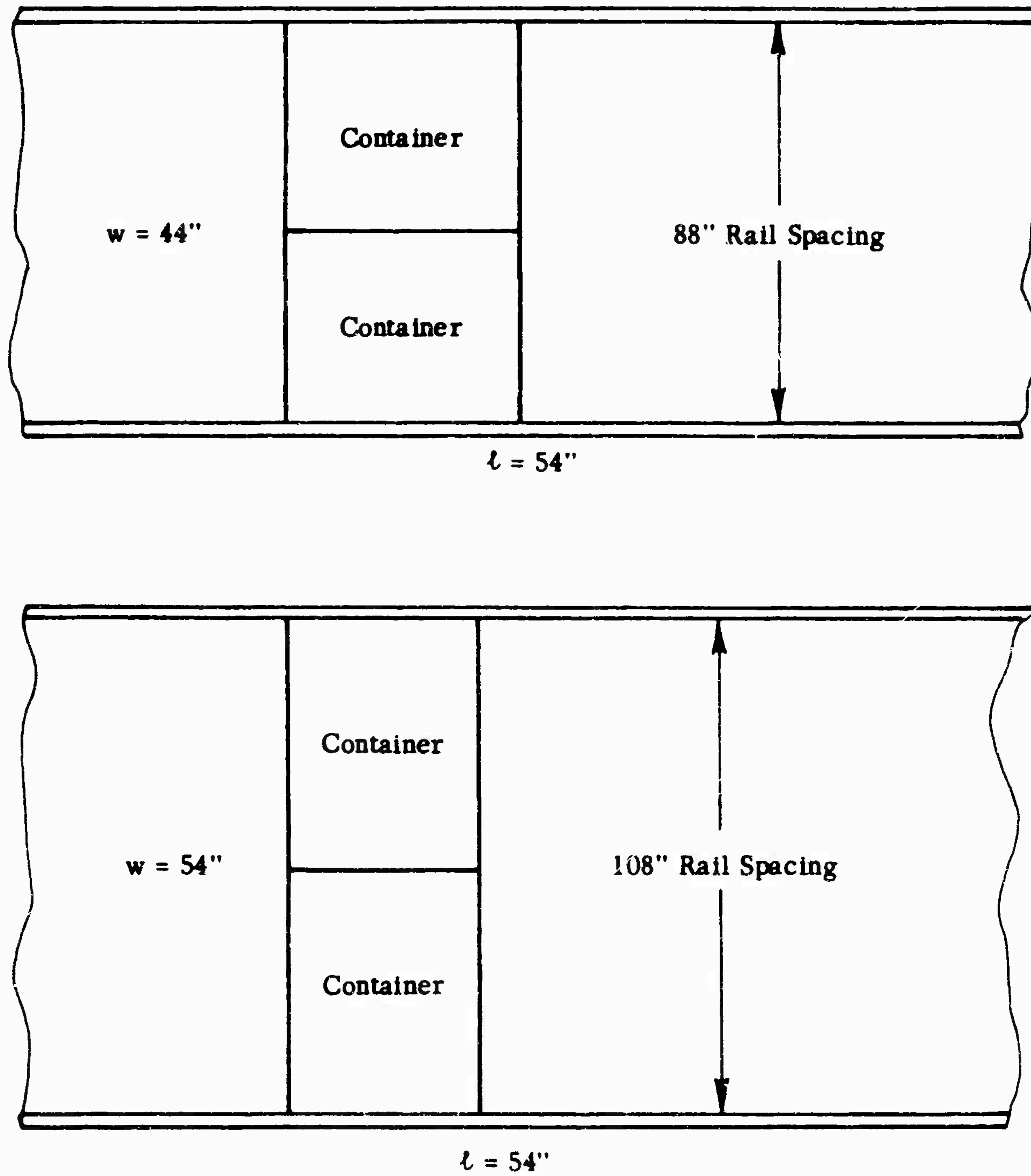


FIGURE 35 ARRANGEMENT OF CONTAINER PAIRS IN AIRCRAFT WITH 88" AND 108" RAIL SPACING

The developed forces are higher for the 108" rail spacing, and should be used in the design calculations. These forces are graphically shown in Figure 36. The vertical corner members are loaded in compression and diagonals are in tension. F_5 is the tensile force tending to separate the containers at the rear top edge. F_v is the downward load applied to the rear of the container lip by the restraining aircraft rail.

DESIGN OF BASE

General requirements for the container base are as follows:

1. Outside dimensions to be 44" x 54"
2. Capable of being rolled on skate wheel and roller conveyors
3. Capable of being forklifted
4. Capable of being locked in 463L aircraft rail system
5. Capable of withstanding required g loadings
6. Minimum cost and weight consistent with the above requirements

Three designs have been considered. They are similar in that they employ plywood for top and bottom decks. The designs are different in the use of metal around the periphery of the base, and in the use of wooden spacers. The general concept for the container base designed with wooden spacer blocks is shown in Figure 37.

Aluminum Extrusion Around Bottom Deck

The aluminum frame member would be extruded to the shape as shown in Figure 38, Section A-A. After cutting and notching, they would be welded into a rectangular frame. Figure 38 shows the sizes and location of the wooden spacer blocks, and the location of the rivets necessary to assemble the base section. Fifty-four rivets, 3/8" diameter, are required due to the low allowable loading (325 psi perpendicular to the grain) of the wooden spacer blocks.

A sectional view of the base design is shown in Figure 39. After making the assembly, the 1/2" plywood bottom deck would be fastened to the aluminum extrusion by means of self-tapping flathead screws or other suitable means.

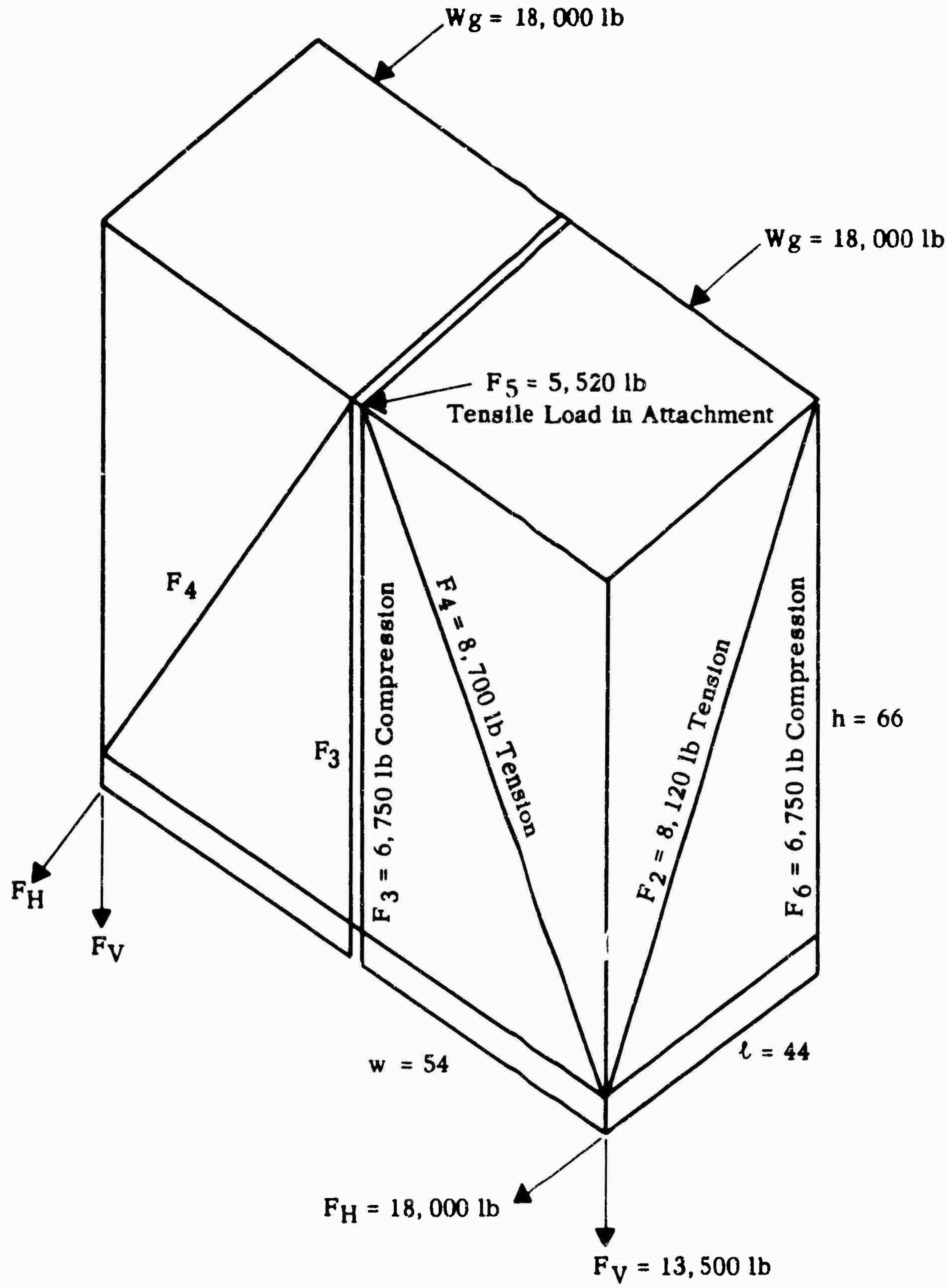


FIGURE 36 FORCES IN CONTAINER FRAME FOR 9G ACCELERATION WHEN ARRANGED FOR 108" AIRCRAFT RAIL WIDTH

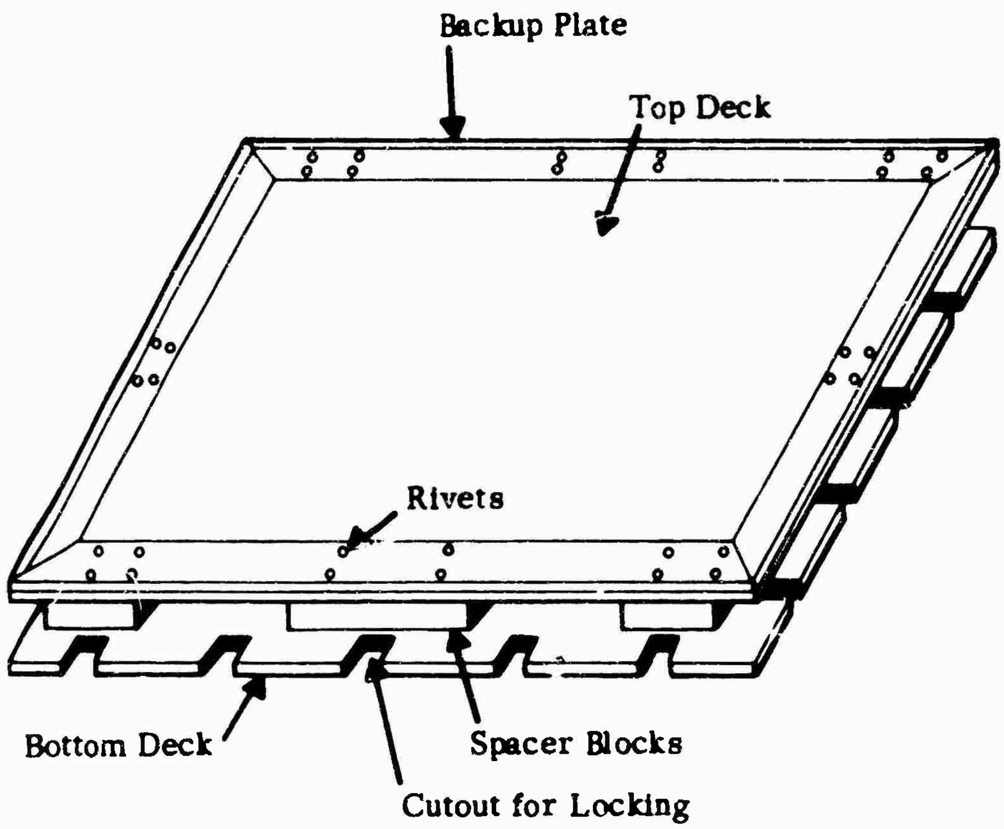


FIGURE 37 GENERAL CONCEPT FOR CONSTRUCTION OF CONTAINER BASE

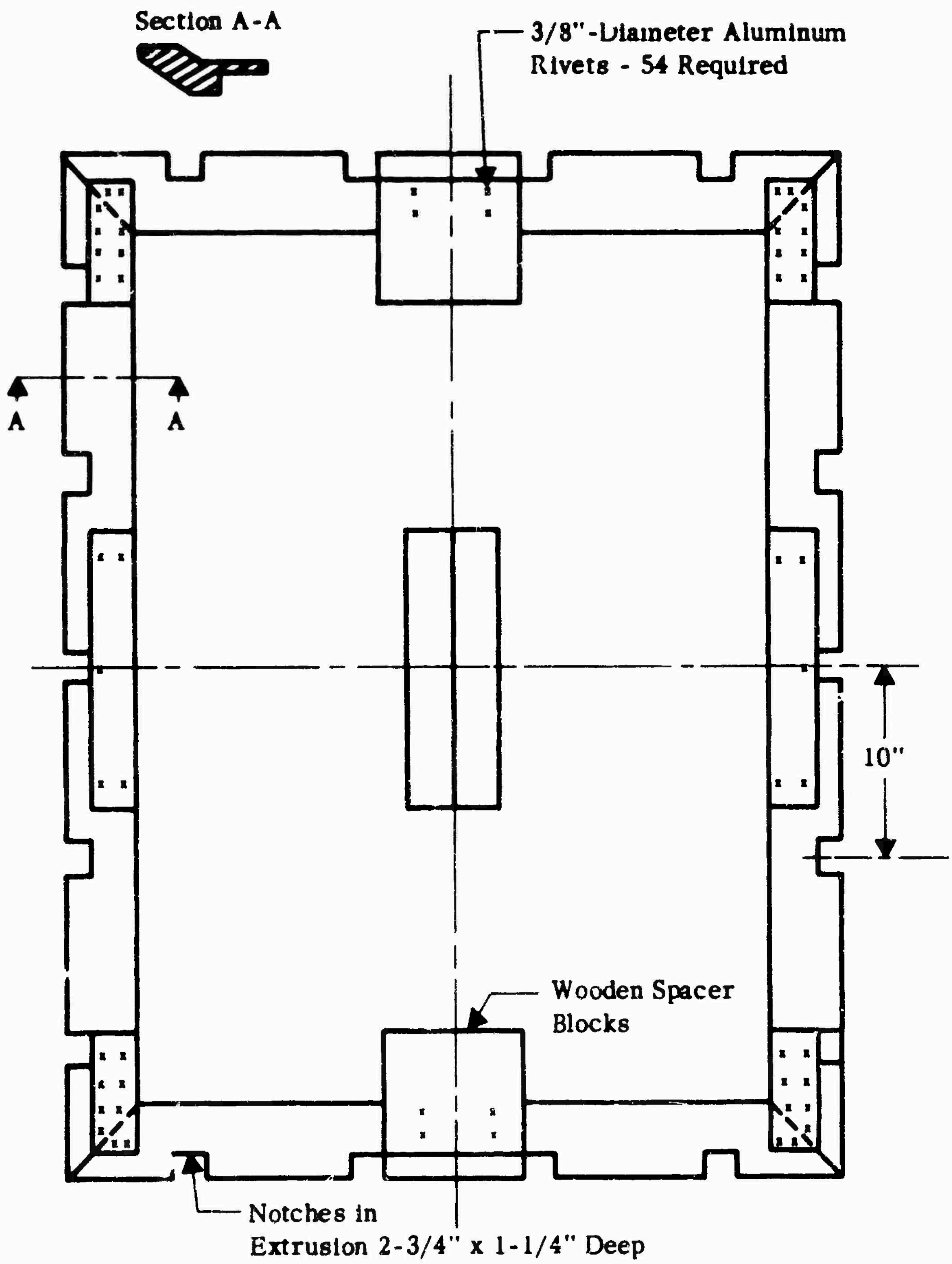


FIGURE 38 ALUMINUM EXTRUSION BASE DESIGN SHOWING SPACER AND RIVET LOCATIONS

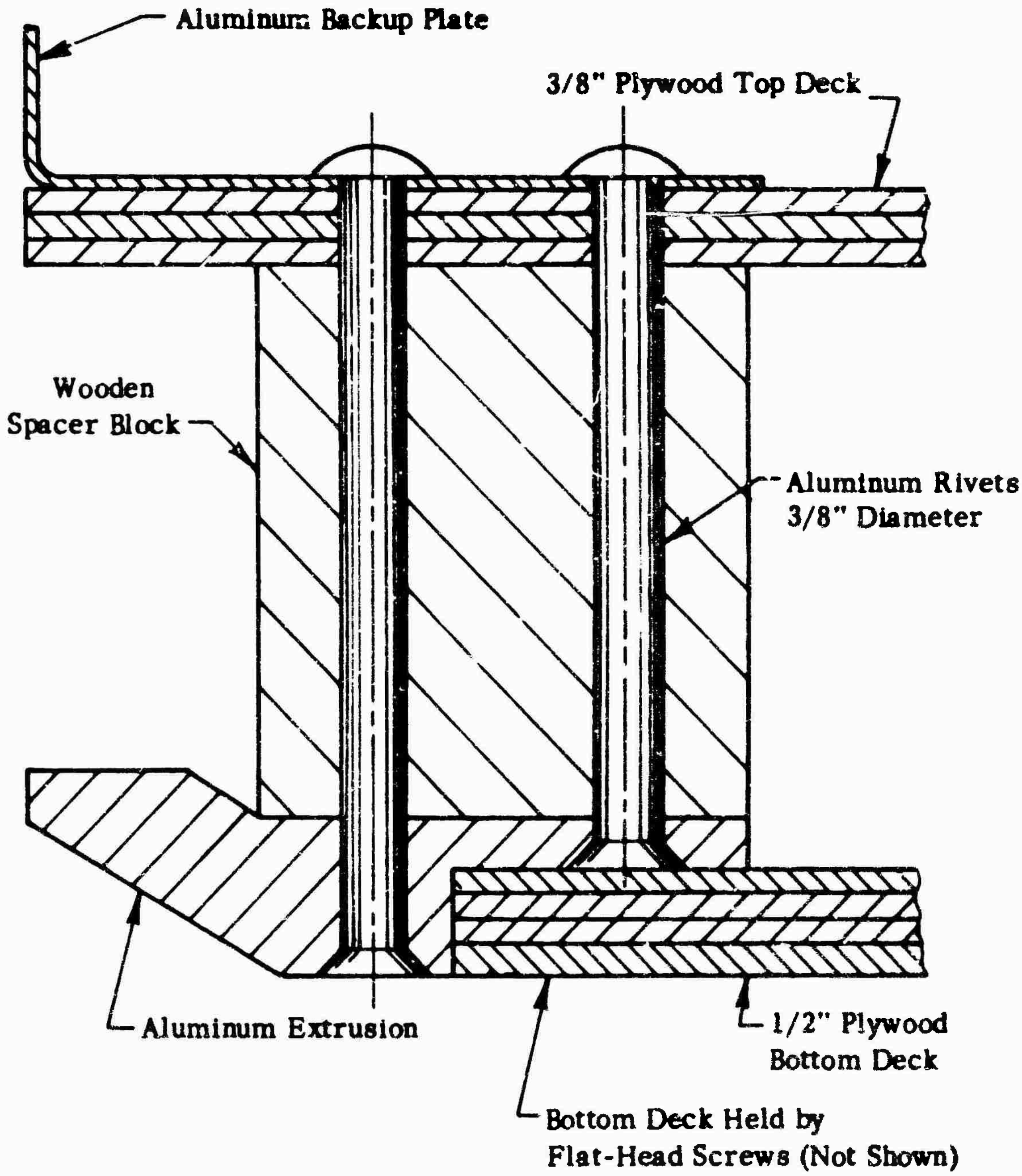


FIGURE 39 SECTIONAL VIEW OF BASE DESIGN WITH ALUMINUM EXTRUSION AROUND THE BOTTOM DECK

Estimated weigh for this base design is 107.5 pounds. Estimated manufacturing cost is shown in Table 19. Detailed estimates are made in Appendix VI.

TABLE 19

ESTIMATED MANUFACTURING COST FOR
EXTRUDED ALUMINUM BASE DESIGN

Cost of Material	$30.55
Labor Cost (85 min @ $3.00/hr)	4.30
Overheat @ 150%	6.45
Manufacturing Cost	$41.30

Steel Reinforced Base Design

This design concept incorporates a fabricated steel frame around the outer edge of the bottom deck with steel rivets for making the assembly. Other features would be essentially the same as the base construction employing the aluminum extrusion. Figures 40 and 41 illustrate details of this design. The cutout section for engaging the restraining bolt in the 463L rail system must withstand an 18,000-pound load. The required strength is obtained by bending and welding tabs, as shown in Figure 41.

Estimated weight for the steel reinforced base is 168 pounds and estimated manufacturing cost is shown in Table 20. Detailed estimates also will be found in Appendix VI.

TABLE 20

ESTIMATED MANUFACTURING COST FOR
FABRICATED STEEL BASE DESIGN

Cost of Material	$28.47
Labor Cost (96 min @ $3.00/hr)	5.50
Overhead @ 150%	8.25
Manufacturing Cost	$42.22

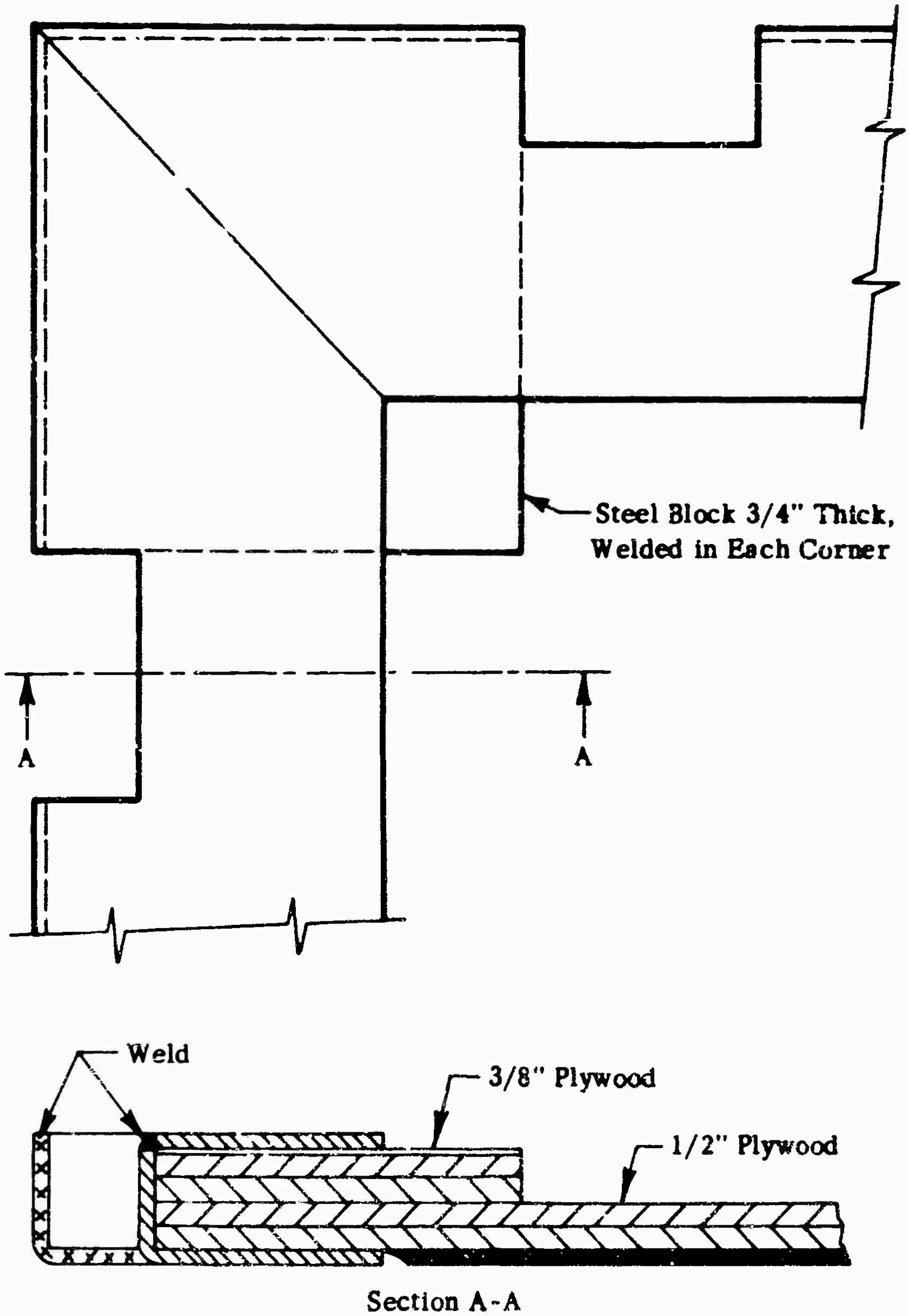


FIGURE 40 CORNER CONSTRUCTION AND SECTIONAL VIEW OF STEEL FRAME AROUND THE BOTTOM DECK

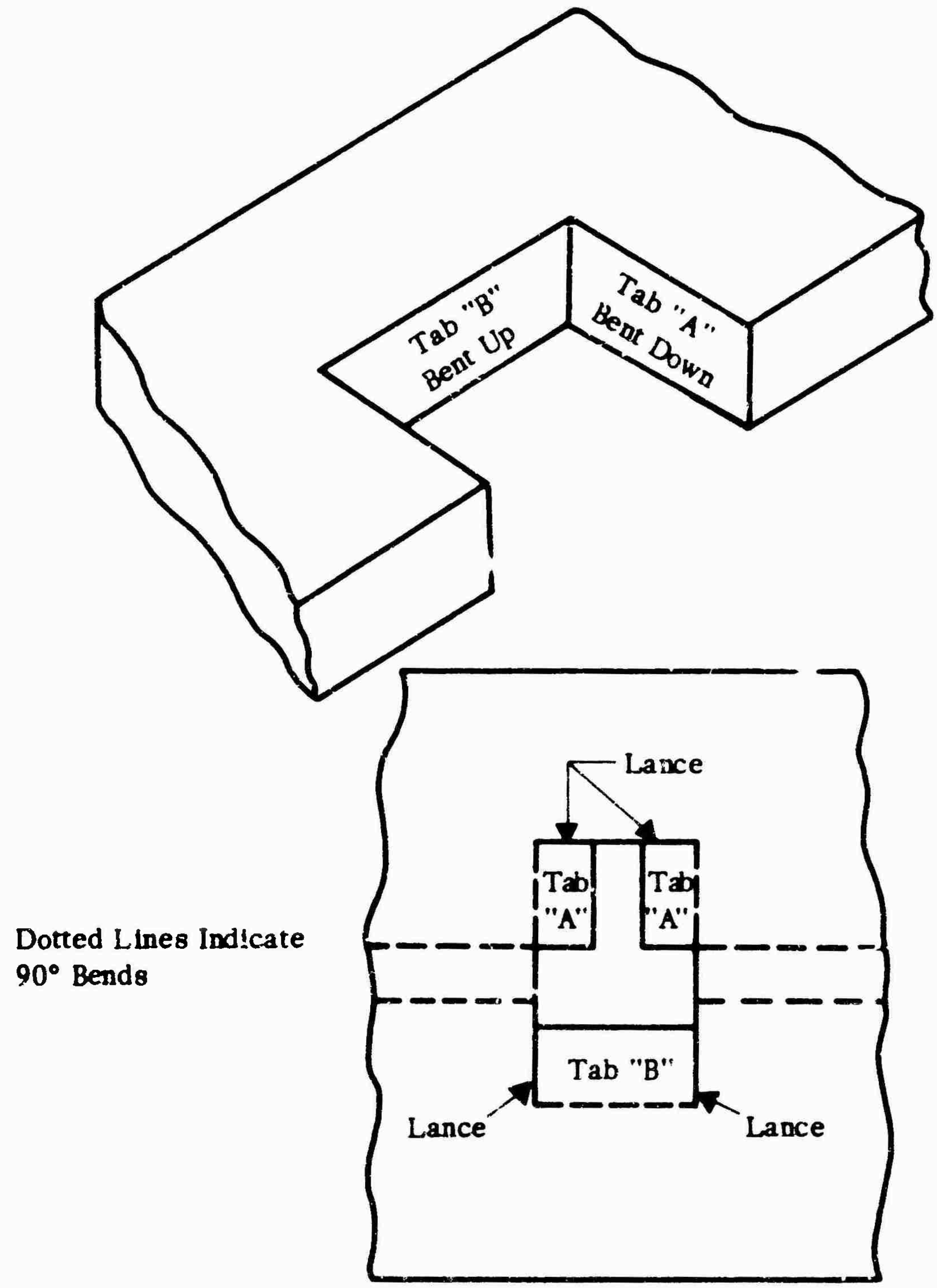


FIGURE 41 CONCEPT FOR FABRICATED STEEL FRAME AROUND THE BOTTOM DECK

Aluminum Extrusion "Channel" Design

A base as shown in Figure 42 can be designed by employing a "channel" shaped aluminum extrusion. This member would replace all of the wooden spacer blocks around the outside edge of the base. The web would be pierced for forklift entries, and the lip would be notched to accommodate the 463L restraining bolts. The aluminum section would be mitred and welded to form a complete frame. Top and bottom decks could be plywood fastened to the extrusion with screws or adhesive. A wooden spacer at the center of the deck (as shown in Figure 38) would be required to sustain loadings on the container floor This spacer also could be fastened in place with an adhesive. The outside spacer blocks, rivets, and considerable labor cost is saved by this design. Estimated weight is 77 pounds and estimated manufacturing cost is shown in Table 21.

TABLE 21

ESTIMATED MANUFACTURING COST FOR ALUMINUM EXTRUSION "CHANNEL" DESIGN

Cost of Material	$18.95
Labor Cost (33 min @ $3.00/hr)	1.65
Overhead @ 150%	2.50
Manufacturing Cost	$23.10

Ranking of Base Designs

All three base designs will meet the operational requirements. On the basis of weight and cost, the preferred base is the aluminum extrusion "channel" design. Weight and cost for the three designs are summarized in Table 22.

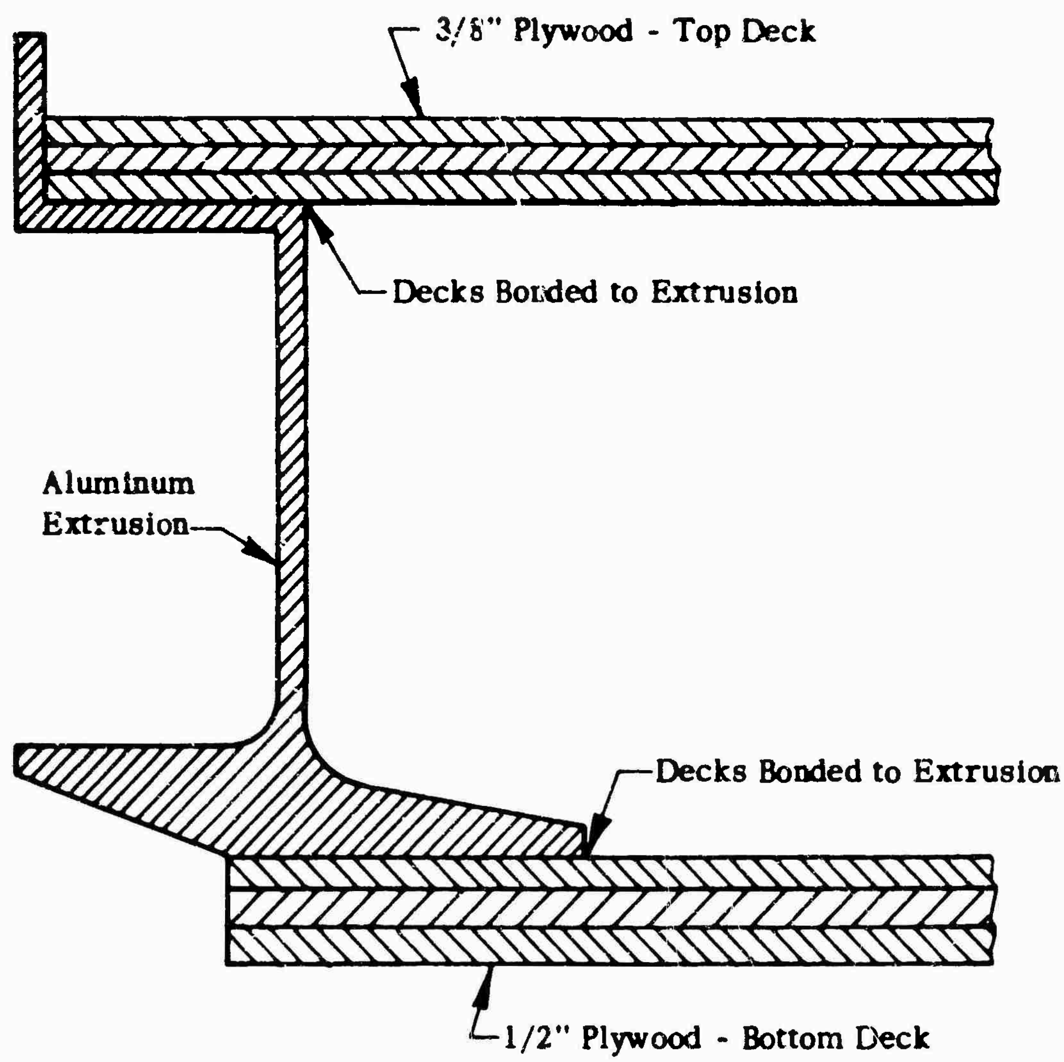


FIGURE 42 SECTIONAL VIEW OF ALUMINUM EXTRUSION "CHANNEL" BASE DESIGN

TABLE 22

SUMMARY OF BASE DESIGNS

	Weight	Manufacturing Cost
Aluminum Extrusion "Channel" Design	77.0	$23.10
Aluminum Extrusion Around Bottom Base	107.5	41.30
Steel Reinforced Base Design	168.0	42.22

DESIGN OF CONTAINER TOP SECTION

A container must protect the cargo it carries in two ways. It must provide adequate protection against such environmental conditions as precipitation, humidity, dust, and to a certain extent, heat and cold. Also, it must restrain the contents against forces encountered in handling and transportation. Two types of container construction have been investigated: one in which the panel supplies both environmental protection and structural strength, and the other where the strength is supplied by a separate framework and the protection is provided by the panel material.

Panel Materials Used Alone

Container panels of solid, laminated, and honeycomb construction have been considered. Appendix IV includes the structural analysis for several representative materials.

In the solid material category, Masonite tempered duolox was investigated. For a required thickness of 1/2 inch, the weight would be 350 pounds, and it would cost $33.50. Plywood is representative of commonly used laminated materials. A 1/2-inch-thick plywood container top section would weigh 160 pounds and the material would cost $17.50.

Sandwich materials are excellent for applications where the strength to weight ratio must be high, as in this container design. However, a construction which would meet the strength and weight requirements would be too high in cost. Paper honeycomb is the lowest cost core material of this type. As shown in Appendix IV, this material would not be satisfactory, due to excessive shear stress. Balsa wood or aluminum honeycomb are acceptable for strength but would cost too much. This type of sandwich core construction will range upward in cost from approximately \$.50 per square foot. At \$.50 per square foot, the material cost for side panels would be \$53.00.

Combination Frame and Panel Construction

The form of construction employing a metal truss-like frame with panels inside the metal structure can be designed to fulfill the requirements. Although it is obvious that developed loads would be shared by the framework and panels, it is convenient to consider the loads as being carried by the frame and the environmental protection being supplied by the panels.

The frame would have to withstand forces, as shown in Figure 36. A frame construction as shown in Figure 43 could be fabricated to attach directly to the channel extrusion or backup plate on the container base. If the material were 6062-T6 aluminum, the angle sections would be 3/16" x 1" x 1", the diagonal straps would be 3/16" x 1", and the two front vertical members would be as shown in the sectional view. The entire framework would be welded. The sliding door, Figure 44, would be fabricated from flat and extruded aluminum sections and would be bonded to the door material by a suitable adhesive. The estimated weight of aluminum in the framework and door is 37 pounds. Table 23 shows the estimated manufacturing cost. Detailed estimates are in Appendix VII.

TABLE 23

ESTIMATED MANUFACTURING COST FOR
ALUMINUM CONTAINER FRAMEWORK AND DOOR

Material cost, frame	\$13.55
Material cost, door	4.30
Direct labor, frame	2.00
Direct labor, door	.50
Overhead @ 150%	3.75
Manufacturing Cost	\$24.10

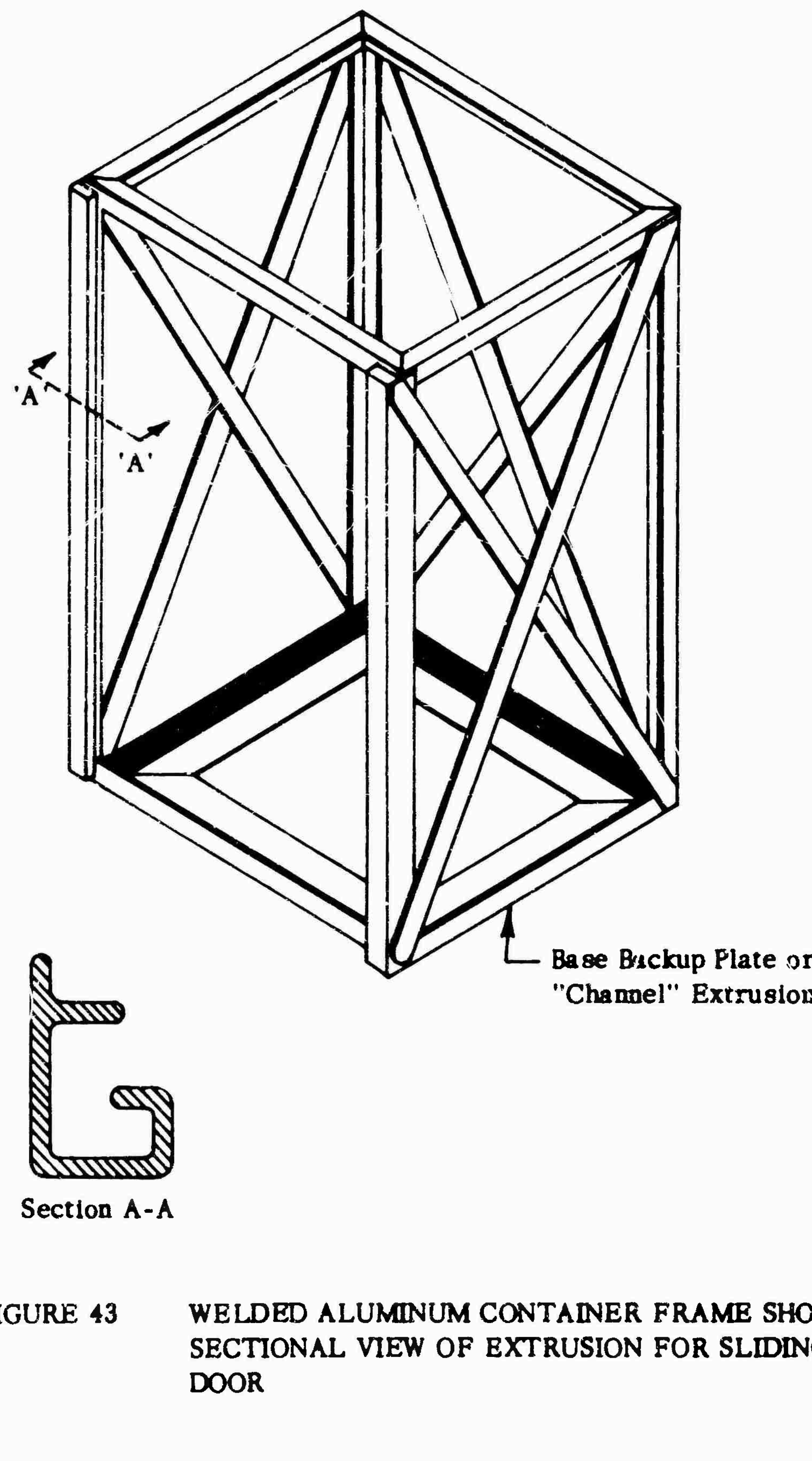


FIGURE 43 WELDED ALUMINUM CONTAINER FRAME SHOWING SECTIONAL VIEW OF EXTRUSION FOR SLIDING DOOR

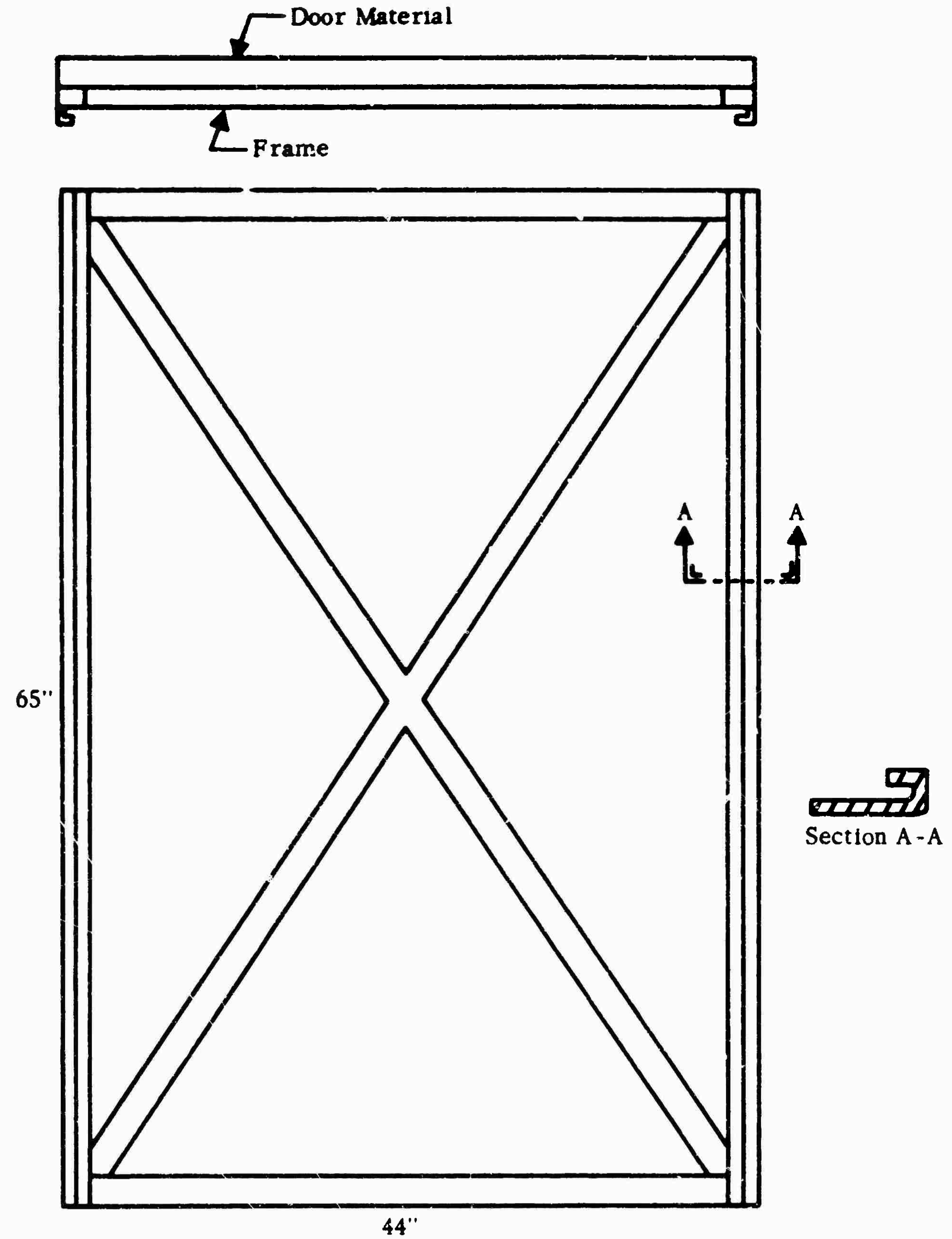


FIGURE 44 WELDED ALUMINUM DOOR FRAME BONDED WITH ADHESIVE TO DOOR MATERIAL

The panel material used for environmental protection can be much thinner than if it were required to carry all the loads. Four possible materials are listed in Table 24.

TABLE 24

REQUIREMENTS FOR SIDE PANEL MATERIALS WHEN USED IN CONJUNCTION WITH ALUMINUM FRAME

Material	Thickness Required (inches)	Weight Unit (lbs/ft^2)	Weight Total (lbs)	Cost Unit ($\$/ft^2$)	Cost Total
V2S	3/32	.44	47	.046	$ 4.90
Tri-Wall Corrugated	1/2	.25	27	.055	5.85
Masonite Tempered Duolox	1/8	.83	88	.079	8.40
Aluminum Sheet	1/32	.43	46	.215	22.90

In addition to the materials listed in Table 24, sandwich construction could be used in conjunction with the metal framework. A discussion of these materials will be found in Appendix V. While it would be possible to employ several such materials for this application, there appears to be no distinct advantage of sandwich materials over the V2S laminated paper board or triple corrugated board. Both of these materials are approved level A packing materials and are used extensively for this purpose.

The panel material would be cut to size and bonded to the inside of the aluminum frame with a suitable adhesive. Three sides, the top, and the door panel would be attached in this manner. The estimated cost for this operation is $.015 for bonding material and $.060 for labor. At 150% overhead rate, the total manufacturing cost for this operation would be $1.65.

METHODS OF CONNECTING TWO CONTAINERS

The tensile force in the top connecting member is 5520 pounds under the influence of 9 g loading. This load is transferred into the aluminum framework. A top connecting link could be made as shown in Figure 45. The link would be designed with one end fixed. The other end would fit over a mating pin on the second container. The link would be spring loaded to hold it in place. Figure 46 shows the arrangement of the connecting links for the 44" x 108" and 54" x 88" configurations. Two such links and pins would be required per container. This method of connection would add approximately 1 inch to the cor ainer height. Hence, the usable volume will be reduced if the 70" height is maintained.

The bottom connection has less load to carry, but must provide for accurate alignment of the two container bases. Since the base serves as the forklift entry and the locking means in the 463L equipped aircraft, a simple locking arrangement that is not a separate attachment would be very difficult to achieve. The proposed attachment shown in Figure 47 is a separate device that could be stowed between the top and bottom decks when not needed. One locking device per container would be necessary.

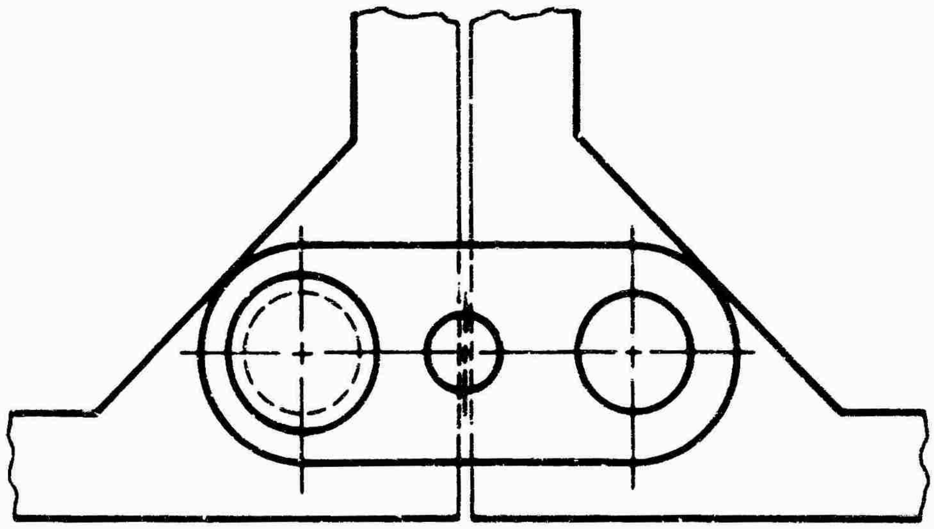
The bottom lock would consist of an aluminum casting with overall dimensions ap proximately as shown in Figure 47. A groove at one end would carry a spring-loaded double bolt. The block would fit between containers as shown in Figure 48, and the bolts would engage mating holes near the corners of the aluminum extrusions.

The estimated manufacturing cost for the required top and bottom connections are shown in Table 25 and tooling is estimated at $500.

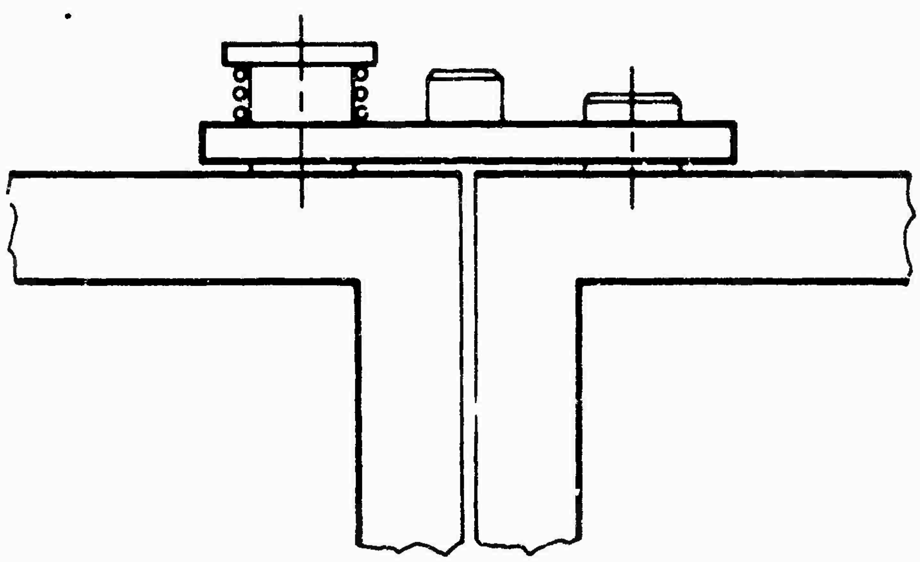
TABLE 25

ESTIMATED MANUFACTURING COST OF CONTAINER CONNECTORS

Top Connector (2 links and 4 posts required per container)	
Material	$ .35
Labor	.50
Overhead	.75
Bottom Connector (1 required per container)	
Material	.50
Labor	.50
Overhead	.75
Total Manufacturing Cost	$3.35

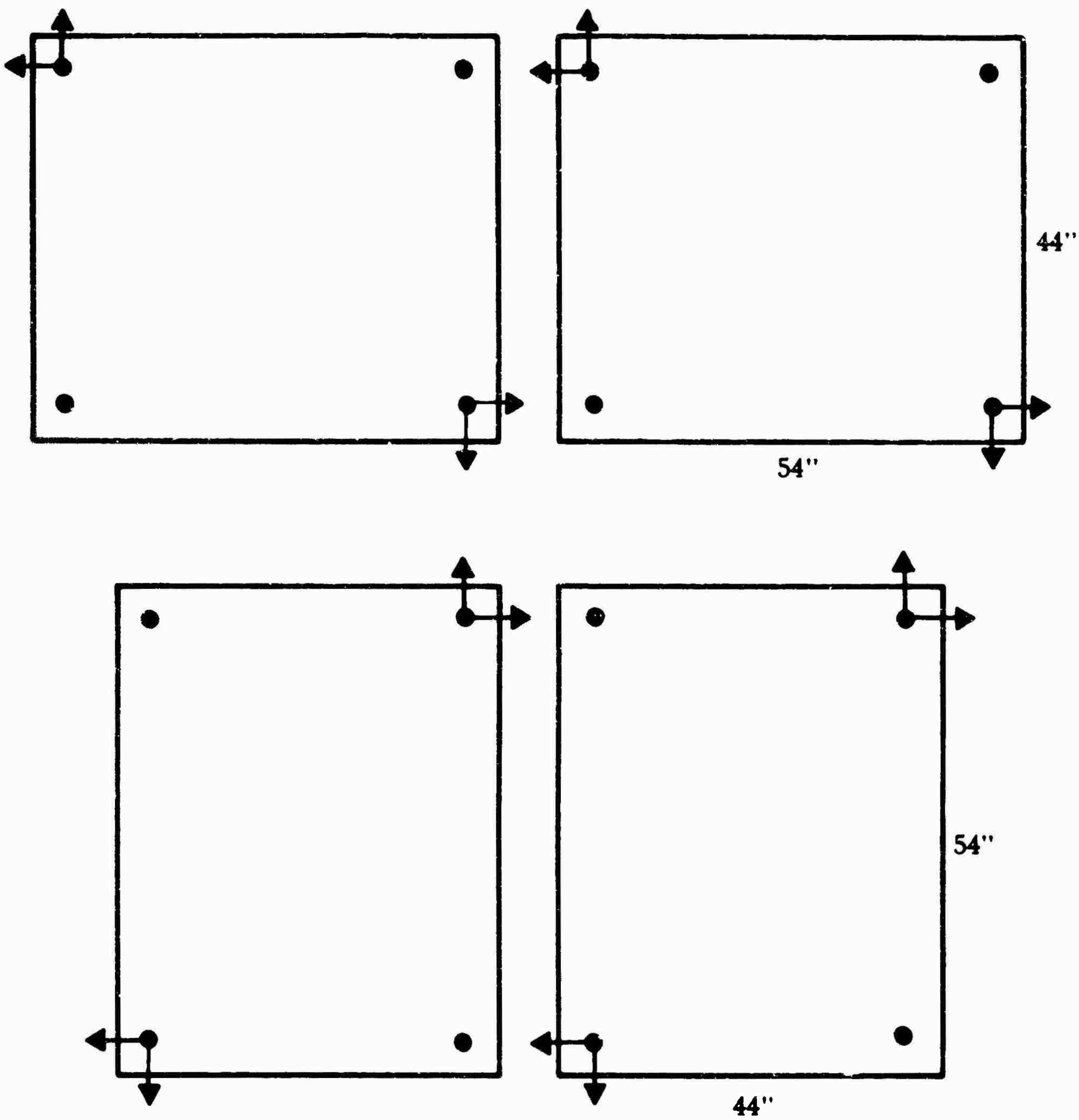


Top View



Side View

FIGURE 45 METHOD OF CONNECTING CONTAINERS AT TOP OF FRAME



Note: Arrows indicate the two possible directions for each link.

FIGURE 46 DIAGRAM ILLUSTRATING ARRANGEMENT OF TOP CONTAINER ATTACHMENTS

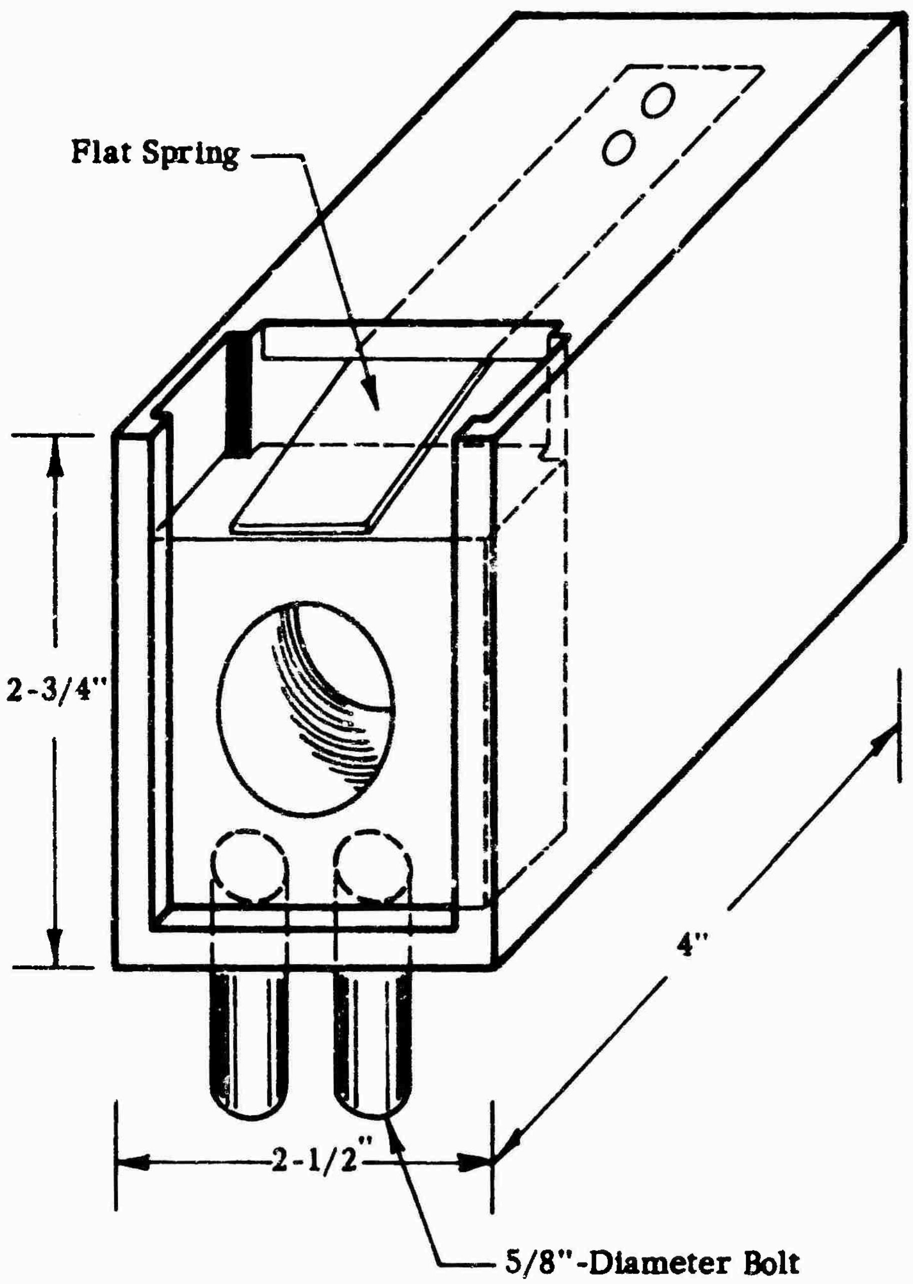


FIGURE 47 CONCEPTUAL DRAWING OF DOUBLE BOLT FOR CONNECTING CONTAINER BASES

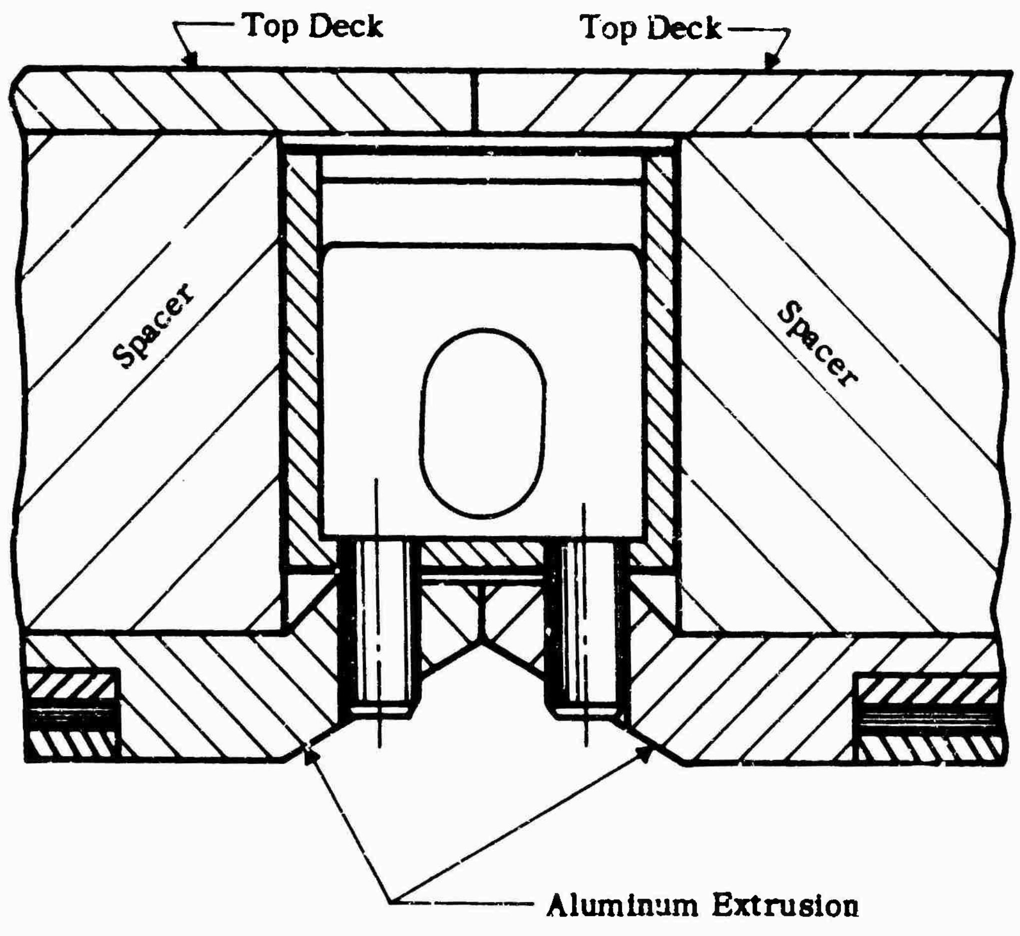


FIGURE 48 METHOD OF JOINING TWO CONTAINERS AT THE BASE WITH DOUBLE BOLT CONNECTOR

SUMMARY OF COSTS AND ESTIMATE OF CONTAINER PURCHASE PRICE

The cost analysis for an acceptable container is tabulated below. This cost is based on materials and manufacturing methods considered to be the lowest for the operating requirements of the container. The estimates have been based on quantities of 5000. This does not permit a high degree of tooling for automatic production methods. However, this quantity seems to be realistic in view of the intended use.

TABLE 26

COST ANALYSIS FOR AIR TRANSPORTABLE CONTAINER WITH ALUMINUM "CHANNEL" - PLYWOOD BASE, ALUMINUM CONTAINER FRAMEWORK, AND V2S PANELS (ESTIMATED FOR QUANTITIES OF 5000)

Item	Material	Labor	Overhead	Total
Base	$18.95	$1.65	$2.50	$23.10
Framework	17.85	2.50	3.75	24.10
Panels & Attaching to Frame	5.05	.60	.90	6.55
Connectors	.85	1.00	1.50	3.35
	$42.70	$5.75	$8.65	$57.10

Manufacturing Cost	$57.10
General and Administrative Expense Plus Profit (10% of manufacturing Cost)	5.70
Total Estimated Purchase Price	$62.80
Estimated Tooling Cost	
Base	$3,200
Frame and Door	1,150
Connectors	500
Total	$4,850

The estimated purchase price exceeds the justifiable cost developed earlier in this report by $4.90. It should be pointed out that the $58.00 justifiable cost is the amount saved when the container is transported over a relatively short ALOC. A long ALOC would produce savings up to an estimated $91.00. All other criteria are satisfied by the design.

It is recommended that sample containers of the preferred design be constructed and tested for compliance with the requirements. Ideas for improving the performance and reducing the cost undoubtedly would evolve.

OTHER CONCEPTS

During the course of this study, several container concepts, in addition to those presented, have been set forth and discussed. They have not received detailed attention for reasons such as: (1) the criteria obviously were not met or (2) construction and techniques involved were not well enough known to estimate cost or performance accurately.

One such concept that fails in this category would employ two sleeve sections stacked vertically. The concept is illustrated by Figure 49. The base could be any construction described earlier in this report. The container would consist of two identical sleeves constructed of any appropriate material such as metal or laminated paper. Each sleeve would be approximately 35 inches high. The procedure for filling the container would be to fill the bottom sleeve, then attach the upper section and proceed to fill to the top. The top of the container would then be put in place and secured. Unloading would follow the reverse procedure.

This design has the advantage of having uniform strength characteristics in all directions because it does not have a side door opening. It could be made variable in volume if more than one length sleeve were used. In addition, it might be made nestable for empty shipment. It would be somewhat difficult to load and unload. Also, the problems of fastening sections together and fastening containers together would be more difficult than with the selected concept. However, this concept is worthy of more careful study as the Army container program progresses.

POSSIBLE FIELD USES

After being used for delivering supplies to the forward area, the empty containers could serve several useful purposes. Door panels or bases without the container

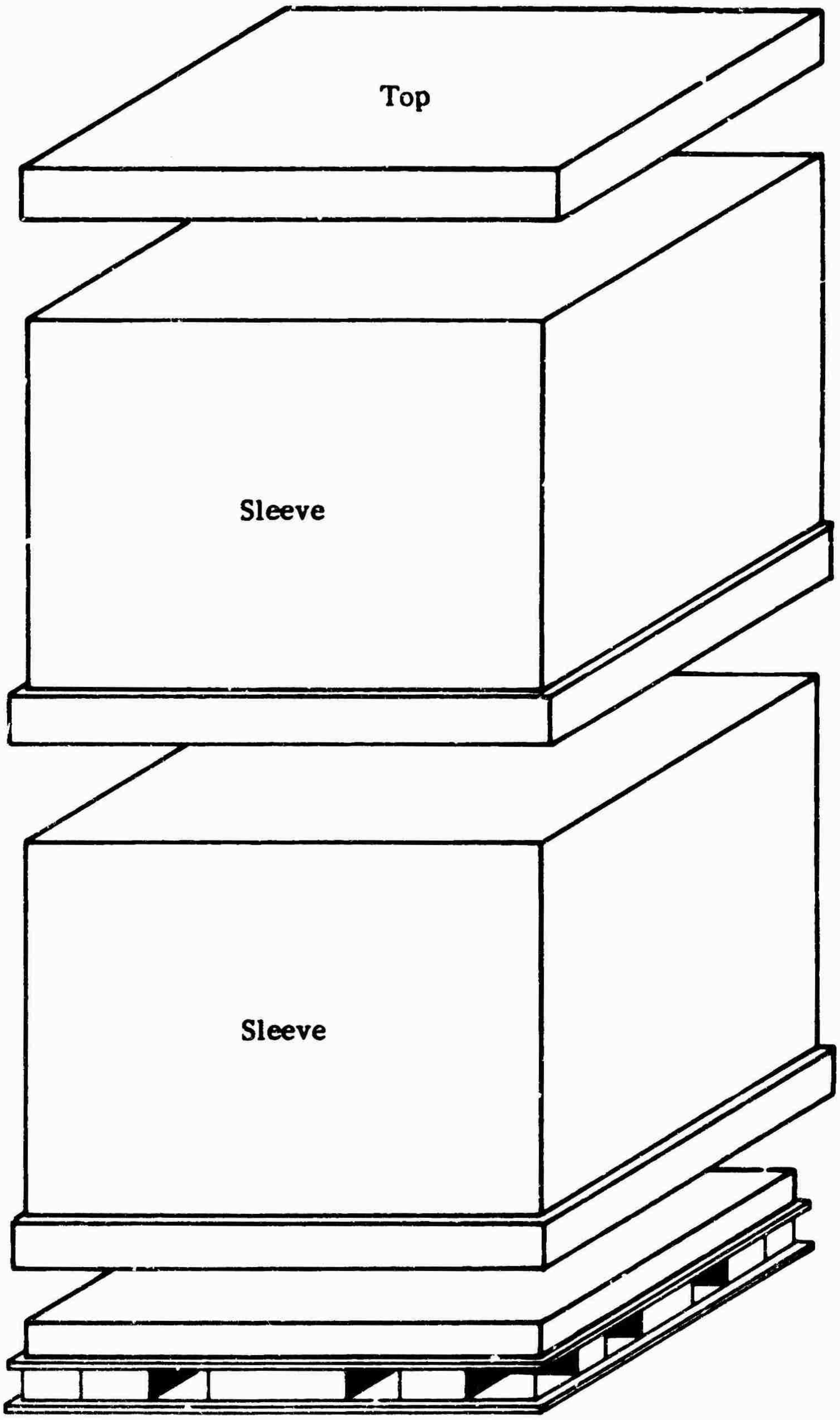


FIGURE 49 EXPLODED VIEW OF TWO-SLEEVE CONTAINER CONCEPT

framework would make good tent flooring. The complete container, either erect or on its side would provide shelter against the elements. It would be large enough for a man to sleep in with some degree of comfort. Containers could be filled with dirt or other material and used for protection against enemy fire.

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APPENDIX I

SAMPLE COMPUTER RUN

AIR TRANSPORTABLE CONTAINER SIZE EVALUATION PROGRAM
VALUES OF VARIABLES FOR THIS CALCULATION RUN ARE AS FOLLOWS
THICKNESS 0.75 INCHES. CONTAINER DENSITY IS 22.0 LBS PER CU FT. BASE HT IS 4 INCHES. MAX LOADED WT IS 2000 LBS
MAXIMUM CARGO DENSITY IS 60.0 LBS PER CU FT. MINIMUM CARGO DENSITY IS 5.0 LBS PER CU FT. FIXED CONTAINER WEIGHT IS 25.0 LBS.
CAPACITIES ARE AS FOLLOWS CV2 7000. CV7 8000. CH47 8000. THE 2.5 TON TRUCK 5000. THE 3/4 TON. 1800
THE 25 TON. 50000

CONTAINER H	W	L	INTERNAL VOLUME	VOLUMETRIC EFFICIENCY	WEIGHT EFFICIENCY	INTERNAL STOWAGE LOSS	LOADED WEIGHT	UNOCCUPIED SPACE	A(I)	VEHICLE NUMBER	B(I)	STEPFUNCTION LOSS	CUBEOUT LOSS
70.0	54.0	44.0	84.253	0.769	0.879	0.121	1601.990	0.712	0.446	1	0.168	788.388	236.863
										2	0.080	360.497	48.268
										3	0.040	349.234	34.423
										4	0.104	791.341	84.010
										5	0.534	0.000	398.010
										6	1.000	0.000	35125.839
SUM OF STEP-FUNCTION LOSS AND CUBEOUT LOSS FOR AIRCRAFT											SUMS	1782.119	329.590
60.0	54.0	44.0	71.341	0.737	0.880	0.147	1456.943	5.675	0.288	1	0.248	784.931	445.600
										2	0.108	585.553	147.784
										3	0.080	442.377	98.897
										4	0.166	719.288	176.577
										5	0.714	0.020	543.054
										6	1.000	0.000	37649.015
SUM OF STEP FUNCTION LOSS AND CUBEOUT LOSS FOR AIRCRAFT											SUMS	1738.080	692.331
50.0	54.0	44.0	58.428	0.703	0.874	0.172	1241.145	0.325	0.053	1	0.356	548.201	750.075
										2	0.184	586.534	341.879
										3	0.190	587.108	236.082
										4	0.257	388.697	336.190
										5	0.947	0.083	756.854
										6	1.000	0.000	30104.388
SUM OF STEP-FUNCTION LOSS AND CUBEOUT LOSS FOR AIRCRAFT											SUMS	1701.921	1347.836
35.0	54.0	44.0	9.880	0.640	0.844	0.212	821.087	0.080	0.648	1	0.288	685.741	307.879
										2	0.087	431.398	57.586
										3	0.047	484.082	28.994
										4	0.511	880.891	848.414
										5	1.000	0.000	1178.973
										6	1.000	0.000	38098.341
SUM OF STEP FUNCTION LOSS AND CUBEOUT LOSS FOR AIRCRAFT											SUMS	1271.168	394.378
35.0	88.0	54.0	79.493	0.718	0.872	0.121	1580.364	0.870	0.398	1	0.257	754.198	479.164
										2	0.087	571.828	66.010
										3	0.080	372.694	36.591
										4	0.119	788.398	102.982
										5	0.642	0.080	437.686
										6	1.000	0.000	35966.434
SUM OF STEP FUNCTION LOSS AND CUBEOUT LOSS FOR AIRCRAFT											SUMS	1080.718	581.766
50.0	88.0	54.0	118.919	0.820	0.868	0.052	1812.729	36.108	0.697	1	0.348	0.000	889.207
										2	0.138	546.707	288.375
										3	0.134	197.480	213.015
										4	0.219	0.000	282.913
										5	0.308	0.000	181.271
										6	1.000	0.000	38098.621
SUM OF STEP FUNCTION LOSS AND CUBEOUT LOSS FOR AIRCRAFT											SUMS	744.176	1387.598
60.0	88.0	54.0	145.199	0.880	0.859	0.080	1900.448	40.868	0.808	1	0.288	0.000	529.336
										2	0.080	581.782	188.669
										3	0.087	129.168	67.989
										4	0.128	0.080	133.543
										5	0.198	0.000	99.552
										6	1.000	0.000	38086.432
SUM OF STEP FUNCTION LOSS AND CUBEOUT LOSS FOR AIRCRAFT											SUMS	686.842	588.794
50.0	36.0	44.0	38.396	0.659	0.844	0.215	888.340	0.080	0.080	1	2.211	398.687	338.485
										2	0.140	411.887	288.385
										3	2.139	488.248	239.870
										4	0.211	398.687	238.881
										5	1.080	0.000	1194.768
										6	1.000	0.000	38874.262
SUM OF STEP FUNCTION LOSS AND CUBEOUT LOSS FOR AIRCRAFT											SUMS	1316.767	778.718

APPENDIX II

METHOD FOR CALCULATING CONTAINER EVALUATION FACTORS

STEP-FUNCTION LOSS

Step-function loss occurs as a result of imperfect matching of total container load with vehicle weight capacity. It is calculated for a container having an internal volume, CIV ft^3 and outside dimensions CH, CW, and CL ft, with relation to a vehicle having cargo space dimensions VH, VW, and VL ft, and carrying capacity CAP, lbs.

The density and probability of cubeout (DC and PC) are determined as illustrated in Figure 9 of the report. Since step-function loss occurs only when the vehicle capacity may be exceeded, it may occur only 1.0 - PC percent of the time. If MN is the maximum number of the container of interest that can be loaded into the vehicle considered because of the fit of that particular container, and if the container tare or empty weight is CT, it is apparent that with cargo of density equal to DC, the full weight of the MN containers equals CAP, or

$$(MN) \quad (CIV \cdot DC) + CT \quad = CAP$$

and the step-function loss is zero. As the cargo density increases from DC, MN containers may no longer be carried, since they would exceed CAP. In fact, at density values between DC and D_{MN-1}, a decreasing step-function loss occurs. D_{MN-1} is the cargo density at which MN-1 containers equal the capacity, or

$$(MN-1) \quad (CIV \cdot D_{MN-1}) + CT \quad = CAP.$$

In like manner, as the cargo density increases from D_{MN-1} to D_{MN-2}, a step-function loss is encountered.

If one takes as an example a DC, of 14.0 lbs/ft^3 calculated in the manner shown in Figure 9, and superimposes a vertical line at that density on Figure 10, it can be seen that, as density varies between 14 and 40 lbs/ft^3, step-function loss occurs. This loss will be the maximum just past DC and decrease until just before D_{MN-1}, at which time it is again zero, since MN-1 containers are all that could be loaded. The loss between any two "exact fits" such as DC and D_{MN-1} is the integral average of the product of the vertical distance of the corresponding shaded step in Figure 10 and the corresponding density. In order to approximate this integral for computation, a straightline segment was taken between the exact fit points instead of the curve in Figure 10. With this simplification, the expected step-function loss between DC and D_{MN-1}, for example, is

$$SFL_1 = CIV \left(\frac{DC + 2D_{MN-1}}{6} \right).$$

In like manner, between D_{MN-1} and D_{MN-2} the loss is

$$SFL_2 = CIV \left(\frac{D_{MN-1} + 2D_{MN-2}}{6} \right).$$

The total expected step-function loss is the weighted sum of the expected loss between the points at which exact fit occurs. An adjusted term is added to take care of the step-function loss between MN containers and the fractional number of containers desired at the maximum cargo density, which is not a density of exact fit as are D_{MN-1} and D_{MN-2} above. Likewise, when the container is of such size that it may weigh 2000 lbs with cargo less than the maximum density, a further adjustment is made to include the step-function loss resulting from a 2000-lb container.

INTERNAL STOWAGE UTILIZATION FACTOR

Internal Stowage Utilization Factor, ISF, as defined in the text, is calculated for evaluation purposes by assuming a linear relationship between ISF and internal volume over the range of capacities of interest. Consequently, ISF is expressed by:

$$ISF = 0.9 - (100 - CIV)\ (.002).$$

This equation closely approximates the predicted ISF curve of Figure 8 from CIV of 40 to 120 cu ft, the range of containers considered herein.

VOLUMETRIC EFFICIENCY

Volumetric efficiency is the ratio of internal container cube capacity and external cubic dimensions. If, for a particular container, h, l, and w are internal dimensions and CH, CL, and CW are the overall exterior dimensions, volumetric efficiency is simply

$$VE = \frac{(h)\,(l)\,(w)}{(CH)\,(CL)\,(CW)}\ .$$

For the evaluation calculations, the overall dimensions were derived by using the internal dimensions plus two effective thicknesses plus, in the case of height, the base height.

WEIGHT EFFICIENCY

Weight efficiency of a particular container, WE, is the expected weight of the cargo contained, WCAR, divided by WCAR plus the weight of the container, CT, or:

$$WE = \frac{WCAR}{WCAR + CT}\ .$$

The expected cargo weight is determined by considering that as cargo density increases, a density is reached above which a particular container will weigh the 2000-lb specified maximum weight. This density, DSMW, is calculated as follows:

$$DSMW = \frac{2000 - CT}{CIV \cdot ISF}$$

where: ISF is the internal stowage factor for that container

and the probability, or expected frequency of its occurrence, PSMW, is:

$$PSMW = \frac{40 - DSMW}{40 - 5}\ .$$

So PSMW percent of the time the container plus contents will weigh 2000 lbs. When the density is between 5 lbs per cu ft and DSMW the container weight varies with density. The average weight of the goods contained divided by the expected total weight, or the weight efficiency, can be expressed as:

$$WE = PSMW\,\frac{(2000 - CT)}{2000} + (1.0 - PSMW)\left[\frac{1}{1 + \dfrac{CT \cdot 2}{CIV\,(ISF)\,(5.0 + DSMN)}}\right].$$

CUBE-OUT DENSITY AND PROBABILITY

Cube-out density and probability are calculated as indicated on Figure 9. In general terms, using the variables described above, cube-out density for a particular container and vehicle is defined by:

$$DC = \left[\frac{CAP}{MN} + CT \right] \left(\frac{1}{CIV} \right)$$

and the probability, or expected frequency of its occurrence is:

$$PC = \frac{DC - 5}{40 - 5} .$$

For both expressions, of course, DC must be between 5 and 40 lbs per cu ft.

ALLOWABLE CONTAINER WEIGHT

A container that provides level A protection replaces much of the packing and unitizing material in a comparable pallet load. These materials include some of the wooden crating, high-grade fiberboard, and the wooden pallet.

The total weight of materials replaced by a container is a function of the size of the container, the proportion of wooden crating replaced, and the type and proportion of heavy fiberboard replaced.

The total weight of replaced material was calculated using the expression below, where

ACW = allowable container weight, or total material replaced, lbs

CIV = container internal volume, ft^3

ISF = internal stowage factor

D = dimension of the average cubic carton

P = fraction of cargo packed in wooden cartons

SMW = the specified maximum weight of the container plus cargo

PSMW = percentage of the time the container weighs the specified maximum weight

CT = container tare weight, lbs

DG = maximum density of the cargo to be carried

Numerical values 1.6, .15, and .44 are weights of materials from Table 6.

$$ACW = \left\{ (1\text{-PSMW})\,(CIV)\,(ISF) + \frac{PSMW}{2}\left[(CIV)\,(ISF) + \frac{SMW-CT}{DG}\right]\right\}$$
$$\times \left\{ \frac{75}{60} + \frac{6D^2}{D^3}\,\frac{P}{2}\left[1.6 - .15\left(\frac{8}{6}\right)\right] + \frac{8D^2}{D^3}\,(1 - P)\,(.44 - .15)\right\}.$$

The first group of terms in the first parentheses expresses the fact that 1 - PSMW percent of the time the container may be filled, and the volume of items contained will be the container volume reduced by the stowage factor. The second group of terms covers the PSMW percent of the time the container reaches maximum weight before being filled. The average volume of items contained when the container is not full is the average between the full container cargo volume and the volume when the container is loaded with cargo of the maximum density.

The 75/60 term in the second parentheses is the weight of pallet replaced per cubic foot of material contained; 75 lbs divided by the 60 cu ft of cargo on the average 40" x 48" pallet. The second group of terms relates to the replacement of wooden cartons with commercial fiberboard; the 6/D term is the sq ft of wood replaced per cu ft of carton of dimension D. The 0.15 lb per ft^2 figure is increased by a factor of 8/6 to reflect the fact that a six-sided wooden carton is replaced by a fiberboard carton with eight effective sides, including flaps. The third group of terms deals with the remaining non-wood crated cartons with 8/D sq ft of material replaced per cu ft of carton. The above expression relates to replacing solid V2S fiberboard, and produces the upper line in Figure 13. The lower line, based on replacing V3C corrugated level A fiberboard, results from an identical equation, except that the 0.44 term in the last group of terms is replaced by the weight per sq ft of V3C, 0.29 lbs per sq ft.

APPENDIX III

DETAILED COST FACTORS FOR TRANSPORTATION, LABOR, & HANDLING

UNITIZED LOAD ON 40" x 48" PALLET

Pallet Buildup

Buildup 1530 lbs/2000 x $3.00	$2.30	
Strapping (33 ft x $.009) + ($3.00/12)	.55	$2.85

Handling & Surface Transportation in CONUS

Load on truck or railroad by forklift .1 hr @ $4.00	.40	
Surface transportation to Air Force pickup point 100 mi @ $.02/ton mi	1.60	
Offload and channel at Air Force terminal .1 hr @ $4.00	.40	
Palletize on Air Force master platforms .05 hr @ $4.00	.15	
Net platform 2 men .3 hr/4 = .15 man-hour @ $3.00	.45	
Load MATS aircraft (assume .1 hr per pallet at FLT rate of $4.00/hr)	.40	3.40

MATS Airlift

Calculated @ 18¢/ton mile for an estimated 1000 miles from pickup point to the East Coast, then at 25¢/lb from the East Coast to France

Weight = 1530 lbs. load + 75 lbs. pallet
+ 1/4 platform weight (300/4)
+ 1/4 MATS netting weight (60/4)
= 1605 + 75 + 15 = 1695 lbs

Transportation Cost	= 1695/2000 x 1000 x $.18 + 1695 x $.25 = $152.50 + $423		$575.50

Overseas Handling & Transportation by Air Force

Offload at overseas APOD (assume .05 hr per pallet load & FLT rate of $4.00/hr)	.20	
APOD terminal handling (assume .05 hr per pallet load & FLT rate of $4.00/hr)	.20	
Load theater transport aircraft (assume .1 hr per pallet load & FLT rate of $4.00/hr)	.40	
Theater airlift (assume 500 miles @ $.18/ton mile) 1695/2000 x $.18 x 500	76.25	77.05

Overseas Handling & Transportation by Army

Offload at Field Army rear area (.05 hr per pallet load @ FLT rate of $4.00/hr)	.20	
Denet platform (2 men for .2 hr = .4 man-hour x $3.00/4)	.30	
Field Army terminal handling (.1 hr per pallet load @ FLT rate of $4.00/hr)	.40	
Load Army aircraft (.05 hr per pallet @ FLT rate of $4.00/hr)	.20	
Tiedown in aircraft (assume 4 pallets per aircraft, requiring 2 men for .3 hr to tiedown) 2 x .3 x $3.00/4	.45	
Army air transport (50 mi @ 175 mph and $260/ hr operating cost) 50/175 x $260/4	18.60	
Offload Army aircraft (.05 hr per pallet @ FLT rate of $4.00/hr	.20	20.35

44" x 54" x 70" HIGH (84 ft^3)
CONTAINER MODULAR WITH 463L SYSTEM

Container Loading

Erecting container .25 man-hour @ $3.00	$ .75	
Filling container 1410 lbs/2000 x $3.00	2.10	
Closing container .1 man-hour @ $3.00	.30	$3.15

Handling & Surface Transportation in CONUS

Load on truck or railroad .1 hr @ FLT rate of $4.00/hr	.40	
Surface transportation to Air Force pickup point (100 mi @ $.02/ton mile)	1.60	
Offload and channel at Air Force terminal (.10 hr @ $4.00/hr)	.40	
Assemble two containers in the 44" x 108" configuration (.2 hr @ $3.00/hr)	.60	
Load MATS aircraft (.1 hr @ $4.00/2)	.20	3.20

MATS Airlift

Calculated @ 18¢/ton mile for an estimated 1000 miles from pickup point to the East Coast, then @ 25¢/lb from the East Coast to France

Weight = 1605 lbs

Transportation Cost = 1605/2000 x 1000 x $.18
+ 1605 x $.25
= $144.50 + $401.25 — 545.75

Overseas Handling & Transportation by Air Force

Offload at overseas APOD (.05 hr @ $4.00/2)	.10	
APOD terminal handling (.05 hr @ $4.00/2)	.10	
Load theater transport aircraft (.1 hr @ $4.00/2)	.20	

Theater airlift (500 mi @ 18¢/ton mile)		
Weight = 1605 lbs		
Cost = 1605/2000 x $.18 x 500	$72.25	72.65

<u>Overseas Handling & Transportation by Army</u>

Offload at Field Army rear area (.05 hr @ $4.00/2)	.10	
Field Army terminal handling (.1 hr @ $4.00)	.40	
Disconnect containers (.05 hr @ $4.00 + .1 hr at $3.00)	.50	
Load Army aircraft (.05 hr @ $4.00)	.20	
Tiedown in Army aircraft	.45	
Army air transport (same)	18.60	
Offload Army aircraft (.05 hr @ $4.00)	.20	20.45

<u>44" x 54" x 70" HIGH (84 ft^3) CONTAINER NOT MODULAR WITH 463L SYSTEM</u>

<u>Container Loading</u>

Erecting container	.75	
Filling container	2.10	
Closing container	.30	3.15

<u>Handling & Surface Transportation in CONUS</u>

Load on truck or railroad	.40	
Surface transportation	1.60	
Offload and channel at MATS pickup point	.40	
Palletize on Air Force master platform	.15	
Net platform	.45	
Load MATS aircraft	.40	3.40

MATS Airlift

Weight = 1605 lbs for container and contents
+ 1/4 master platform (300/4)
+ 1/4 MATS netting (60/4)
= 1605 + 75 + 15 = 1695 lbs

Transportation Cost = 1695/2000 x 1000 x $.18
+ 1695 x $.25
= $152.50 + $423 — $575.50

Overseas Handling & Transportation by Air Force

Offload at overseas APOD	$ .20	
APOD terminal handling	.20	
Load theater transport aircraft	.40	
Theater airlift (500 mi @ $.18/ton mile)		
1695/2000 x $.18 x 500	76.25	77.05

Overseas Handling & Transportation by Army

Offload at Field Army rear area	.20	
Denetting platform (same as pallet)	.30	
Field Army terminal handling	.40	
Load Army aircraft	.20	
Tiedown in Army aircraft	.45	
Army air transport. Assume aircraft can transport 4 pallets @ 1695 each		
Cost = 50/175 x $260 x 1/4	18.60	
Offload Army aircraft	.20	20.35

44" x 54" x 60" HIGH (71 ft^3) CONTAINER
MODULAR WITH 463L SYSTEM

Container Loading

Erecting container	.75	
Filling container (1285/2000 x $3.00)	1.95	
Closing container	.30	3.00

Handling & Surface Transportation in CONUS

Load on truck or railroad	$ .40	
Surface transportation to Air Force pickup point	1.60	
Offload and channel at terminal	.40	
Assemble two containers	.60	
Load MATS aircraft	.20	$ 3.20

MATS Airlift

Calculated on same basis as other loads

Weight = 1450 lbs

Transportation Cost = 1450/2000 x 1000 x $.18
+ 1450 x $.25
= $130.50 + $362.50 — 493.00

Overseas Handling & Transportation by Air Force

Offload at overseas APOD	.10	
APOD terminal handling	10	
Load theater transport aircraft	.20	
Theater airlift, 1450 lbs for 500 miles	65.30	65.70

Overseas Handling & Transportation by Army

Offload at Field Army rear area	.10	
Field Army terminal handling	.40	
Disconnect containers	.50	
Load Army aircraft	.20	
Tiedown in Army aircraft	.45	
Army air transport	18.60	
Offload Army aircraft	.20	20.45

APPENDIX IV

STRESS ANALYSIS

The maximum weight of container and contents has been established at 2000 pounds. The allowable container weight is approximately 200 pounds, of which over 50% will be concentrated in the base. Thus, the empty container will have a low center of gravity. For the purpose of these calculations, it has been assumed that the container is completely filled with cargo of uniform density and that the 2000-pound force acts through a point at the center of gravity of the cargo. Hence, the calculations are conservative by an amount not exceeding 10%.

Since it was determined in a preliminary investigation that the forward 9 g loading is the most severe, all the structural requirements are based on a 2000 pound x 9 g = 18,000 pound loading distributed over the forward face of the container. The face that is forward (44 or 54 by 66) is that face that yields the greater loading or the higher stress on the member in question. In the instance of calculations using the force analysis in the report, dimensions w or ℓ were chosen so as to give the higher member force.

The following calculations are presented in example form, showing the governing equations, the reference, if any, and a sample calculation. Where other material selections are possible, only the final result is given.

NOMENCLATURE

In addition to the dimensional notation given in the force analysis in the report, other additional general notations are used as follows:

σ	=	material stress	pounds/sq in
E	=	material Young's modulus	pounds/sq in
p	=	distributed loading	pounds/sq in
t	=	thickness	inches
y	=	deflection	inches
τ	=	shear stress	pounds/sq in

Specific notations with respect to the particular references cited are defined as they are presented.

FRONT PANEL - SOLID

In designing large, thin plates, consideration must be given to the possible development of membrane stresses in addition to the bending stresses. If the deflection at the middle of a plate under a loading is greater than half of the plate thickness, then membrane stresses are developed. If deflections are many times the plate thickness, then the membrane stresses predominate, and the type of analysis used to determine the stresses must be correspondingly appropriate for any case.

From Formulas for Stress and Strain[1], page 203, Case #36, for the deflection at the center of a rectangular plate, assuming small deflections

$$y_{max} = \frac{0.144\, p(\ell)^4}{ET^3(1 + 2.21\alpha^3)}$$

In the above equation α = sides ratio, $\frac{w}{h}$.

In this case, for example, for Masonite

$E = 1 \times 10^6$ psi

$t = 1/2$ inch estimated

$\alpha = \frac{54}{66}$

$p = \frac{18,000}{(54)(66)}$.

The deflection is 21.8 inches. Clearly, these plate equations are not applicable to this type of panel. Furthermore, the additional data from Formulas for Stress and Strain are not extended far enough to include this size plate. Theory of Plates and Shells[2], page 427, presents the curves describing the distribution of stresses between the bending mode and the diaphragm mode. To be noted for comparison is the curve for pure bending.

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1 R.J. Roark, Formulas for Stress and Strain, 3rd edition, McGraw-Hill Book Company, Inc., New York, 1954.

2 S. Timoshenko and Winowsky-Krieger, Theory of Plates and Shells, McGraw-Hill Book Company, Inc., New York, 1959.

Again, assuming a 1/2-inch Masonite panel, and using the curves, but extending by extrapolation to a value of the parameter

$$\frac{p\,w^4}{E\,t^4} = 685,$$

at the center of the panel

σ membrane = 1800 psi

σ bending = 1245 psi

for a total stress of

$$\sigma_T = 3045.$$

This is to be compared to the ultimate strength of Masonite (in 1/8-inch thickness) of 6300 psi. The deflection for this case is determined from equation (252) of Theory of Plates and Shells:

$$p = \frac{y\,E\,t^3}{0.73w^4} + \frac{y^3\,E\,t}{0.516w^4}$$

or, $y = 3.51$ inches,

which is a reasonable center deflection. Also, from the same curves, the total (membrane only) stress at the edge of the panel is 2000 psi, or a tensile load of 1000 pounds per running inch. This would dictate the design of the edge attachment.

Consider, now, the use of paper liners laminated to any required thickness. In particular, a 60-pound liner has an average strength of 5480 psi (machine and cross-machine direction) in a single sheet thickness of 0.017 inches, and

$$E = 0.3 \times 10^6 \text{ psi}.$$

Evaluating the same parameter, for example, for $t = 1/2$ inch,

$$\frac{p\,w^4}{E\,t^4} = 2286,$$

which is far beyond any reasonable extrapolation of the curves. Therefore. from Theory of Plates and Shells. page 420. pure membrane stresses are given by equation 251. and deflection by equation 250.

(It should be noted that in some cases only square plates are considered. but reasonable comparison to almost square rectangles can be made using the characteristic small dimension of the rectangle.)

$$\sigma \text{ membrane} = 0.396 \sqrt[3]{\frac{p^2 E w^2}{t^2}} \quad \text{and}$$

$$y = 0.802\, w \sqrt[3]{\frac{p\, w}{E\, t}} .$$

Evaluating these for the paper gives

σ = 1755 psi

Y = 5.29 inches.

which are very reasonable.

For σ = 2740, or one half yield. t = .26;

σ = 5480. t = 3/32.

For plywood, and taking into account the grain direction of the least available area,

σ (proportional limit) = 7000 psi. and t = 3/8 inch.

If only 3500 psi were allowed, t = 1 inch, approximately.

SIDE PANELS - SOLID

Although the front panel design appears to be most critical from strength considerations. the side panels are more critical because of shear buckling.

From Buckling Strength of Metal Structures.[1] pages 393-395. the case of pure shear of thin panels is presented. In the container. the loading does not produce pure shear. but the same resulting mode of failure. diagonal ripples. will appear. On each side panel of a container. the shear load is 9000 pounds.

The critical shear stress at which the diagonal buckling will occur is

$$\tau_c = \frac{\pi^2 E t^2}{12(1 - \nu^2) w^2} \left(5.34 + \frac{4}{\alpha^2}\right)$$

where ν = Poisson's ratio

α = length to width ratio > 1.0.

For Masonite, $w = 54$. $\ell = 66$. $E = 1 \times 10^6$, $\nu = 0.3$. $t = 1/2$. the developed shear stress is 333 psi. and $\tau_c = 619$ psi. Therefore. the panel will not buckle. For paper. however. because of the lower E and assuming $t = 1/4$ inch. $\tau_c = 47$ psi. The paper will buckle. Even if t were 1/2 inch. the lower E is controlling; τ_c = 186 psi and would still be less than the developed stress. Clearly. external diagonal ribs would be required to prevent buckling.

FRONT PANELS - HONEYCOMB

Design Handbook[2] has developed all of the required equations for this type of construction. The skin (or face) stresses are given by

$$\sigma_f = \beta p w^2 \frac{1}{t_c t_f}$$

where t_f = skin thickness

T_c = core thickness. limited to 1 inch maximum

β = dimensional parameter.

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1 F. Bleich, Buckling Strength of Metal Structures, McGraw-Hill Book Company, Inc., New York, 1952.

2 Hexel Products. Inc., Design Handbook, Brochure E.

Typically, if $\sigma = 30,000$, $t_f = .0314$. Since σ is directly proportional to $1/t_f$, other stresses and thicknesses can be found directly from this one example by noting that

$$\sigma_f t_f = 941 = \text{constant.}$$

The core shear stress is given by

$$\tau_{core} = \frac{2\gamma p w}{t + t_c}$$

where $t = t_c + 2t_f$ and $\gamma = .455$. Since the core shear stress is not very sensitive to changes in facing thickness, τ_{core} will remain essentially constant at about 120 psi. This exceeds, by about a factor of 3, the allowable shear stress of any paper honeycomb core. Metal, or, say, balsa wood cores must be used.

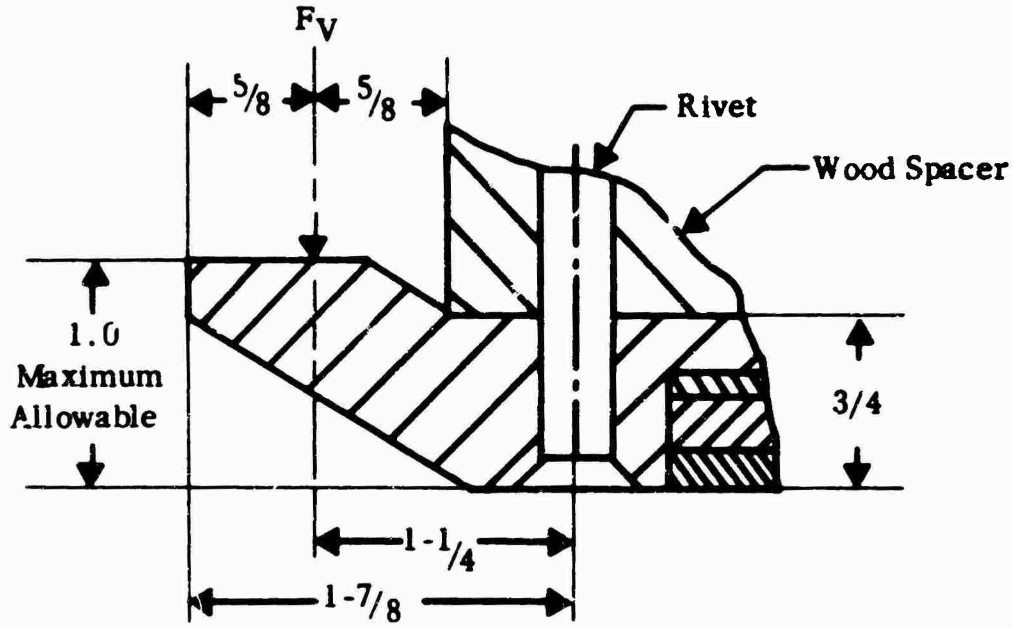
BASE

Bottom Plate

The critical area of the base is the rearmost lip on the bottom section where F_V, the vertical restraining force, equals 13,500 pounds. Only the last section of lip is conservatively assumed to carry the entire load. After a preliminary investigation of this particular structure, the section shown was evolved. The lip is 6 inches long.

The bending moment in the lip at the location of the rivet, which is the worst location, is

$$M = 13,500 \times 1.25 \text{ pound inches.}$$



The moment of inertia of the section

$$I = \frac{b\,h^3}{12} = \frac{(6)(.75)^3}{12},$$

and the developed bending stress is

$$\sigma_B = \frac{Mc}{I} \quad \text{where } c = h/2$$

$$= 30,000 \text{ psi}.$$

An adequate material choice here is 6062-T6, with a yield of 40,000 psi. It is not desirable to design to a higher stress because of the stress concentration at the rivets.

The rail pin applies an aft load of 18,000 pounds at any one notch in the bottom plate of the base. Conservatively, it is assumed that because of positioning it is possible that only one rail pin engages a container. If the bottom plate is extruded aluminum, the face of the notch presents more than 0.75 square inch contact area to the pin, and the compressive stress is 40,000 psi, or less.

If the bottom plate is composed of plywood with a 1/8-inch-thick sheet steel wrapped around it, the wood does not effectively carry any load and the steel area is 7/16 square inch. The developed compressive stress is 18,000 ÷ 7/16, or 41,200 psi. The shear stresses are nominal.

Spacers and Rivets

Assuming fir wood spacers, the entire forward load of 18,000 pounds must be taken in shear in the rivets (or bolts) and eventually in direct bearing stress on the spacers, which have an allowable bearing stress of 325 psi. The spacers are approximately 2-3/4 inches high, giving a required contact area between rivet shanks and wood of 20.2 square inches. If 3/8-inch rivets are used, 54 rivets are needed; if 1/2-inch, 41 are needed. Also, if oak is the spacer material with a corresponding 500 psi allowable bearing stress, 35 or 27 rivets are correspondingly required.

The placement of rivets is adjusted to provide a sufficient number in each corner to withstand the F_v = 13,500 pounds. For example, assuming a working stress of 15,000 psi in direct tension, 0.90 square inch of rivet are required in each corner; that is, five 1/2-inch or approximately eight 3/8-inch rivets.

Top Deck (Container Bottom)

With the required forklift spacing, the longest unsupported span in the 3/8-inch-thick plywood container bottom is 14 inches. Assuming simple beam action (with built-in ends) and orienting the plywood face grain to span the 14 inches, the developed stress is

$$\sigma = \frac{p \ell^2}{12 Z}$$

where p = 11 psi distributed load at 13 g

ℓ = 14 inches

Z = .246 inch^3 per 12-inch width[1]

= .0205 inch^3 per inch of width

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1 Fir Plywood Technical Data Handbook, Douglas Fir Plywood Association, Tacoma, Washington, 1960, Revised, 1961.

and $\sigma = 8750$ psi.

The plywood strength is marginal in this case.

APPENDIX V

SANDWICH MATERIALS SUITABLE FOR SIDE PANELS INSIDE A SUPPORTING FRAMEWORK

Sandwich construction provides a means of achieving substantial rigidity in a panel material. When the sandwich is subjected to load, the facing skins of the sandwich bear the stresses. If the skins are close together, such as 1/8 inch, the skins are highly stressed when the panel is loaded and the sandwich panel is bent and flexed quite readily. As the distance between the facing skins is increased, however, the stresses in the skins become lower for a given loading and the sandwich panel is stiff and rigid. The purpose of the foam or honeycomb core is really to hold the skins apart. Sandwich constructions, therefore, provide panels of low weight and high rigidity. Other properties of sandwich panels, such as puncture resistance, depend in large part upon the qualities of the skin materials used. For example, Kraft paper skins would have poor puncture resistance, whereas more expensive skins, such as aluminum sheet or glass/resin sheets, would have good puncture resistance.

Sandwich panels can be discussed from the standpoint of the core material or the skin material used in their construction.

WOOD CORES

The early sandwich materials consisted of wood veneers faced with heavy Kraft paper. At one time U.S. Plywood made a sandwich panel material called Tekwood, but this product has been discontinued. It consisted of wood veneer about 1/8 inch thick, faced on both sides with heavy Kraft paper. The product had good rigidity and was used in applications where inexpensive, expendable rigid panels were needed.

Similar sandwich materials are made on the West Coast and are used in the construction of produce boxes. The trend for this application is away from the use of paper skins. These are being replaced with plastic sheets to make a sandwich material that is less affected by water.

Plywood can be considered a sandwich material, as it consists of a wood core faced with wood veneer. The current cost of 1/4-inch shop-grade plywood is $69/1000 square feet.

FOAM CORES

Many foamed resins, such as rigid polyurethanes and polystyrene, have been used to make lightweight sandwich materials, and they are manufactured in a fairly broad range of panel thickness and density. One such construction consists of a foamed resin core faced with Kraft paper. This panel is lightweight and rigid, but it is not particularly puncture resistant. A typical construction is a 1/4-inch-thick sandwich panel which consists of a 4-pound-per-cubic-foot-density foam core faced on both sides with 42-pound Kraft paper. The cost of this product is 5.5 cents per square foot.

In a 2-pound-per-cubic-foot density, the material cost of rigid polyurethane foam is approximately 8 cents per board foot.

HONEYCOMB CORES

Honeycomb can be manufactured from a variety of sheet materials, including paper, thin aluminum, etc. Paper honeycomb has been used extensively to make lightweight, inexpensive sandwich panels. Paper honeycomb faced with Kraft paper produces a stiff, rigid panel which has good energy-absorbing properties. It has been used frequently by the military as a cushioning material to protect airdropped cargo.

Paper honeycomb has been used in both the impregnated and unimpregnated condition. The honeycomb is frequently impregnated with phenolic resin to improve its strength, water resistance, etc. Typical costs of paper honeycomb are:

3/4" Cell Size

Phenolic resin, impregnated	- 1/2" thick = \$.055/sq ft
	- 1" thick = \$.081/sq ft
Phenolic resin, unimpregnated	- 1/2" thick = \$ .03/sq ft
	- 1" thick = \$.042/sq ft

SKIN MATERIALS

A wide variety of skin materials can be applied to the core materials discussed above to produce special sandwich materials. These include paper, phenolic resin impregnated paper, phenolic resin impregnated cotton fabric, metal sheets, glass-reinforced plastics, and even thin plywood.

APPENDIX VI

DETAILED COST ESTIMATE FOR CONTAINER BASE

ALUMINUM EXTRUSION DESIGN - LOTS OF 5000

Extrusion - ALCOA Alloy #6062-T6

Weight = 2.285 lbs/ft

= 37.3 lbs/container

Cost = \$.47/lb (30,000-lb quantity)

= \$.47 x 37.3 = \$17.50/container

Rivets - ALCOA Alloy #1100

3/8" x 4-1/2" 54 required

Unit Weight = .05 lb

Weight = 54 x .05 = 2.7 lbs/container

Cost = 2.7 x \$.82 = \$2.20

Wood Spacers - Douglas Fir

7.25 db ft required

Weight = 7.25/12 x 28 lbs/ft^3 = 16.9 lbs/container

Cost = \$.10 x 7.25 = \$.72/container

Bottom Deck Board - 1/2" Plywood, Exterior Grade

Area = 13.6 ft^2

Weight = 1.5 lbs/ft^2 x 13.6 = 20.4 lbs/container

Cost = \$.165 x 13.6 = \$2.23

Top Deck Board - 3/8" Plywood. Exterior Grade

Area = 16.5 ft^2

Weight = 1.1 lbs/ft^2 x 16.5 = 18.2 lbs/container

Cost = \$.13 x 16.5 = \$2.15/container

Backup Plate - Aluminum 1/8" x 5"

Weight = .625 x 196 x .1 = 12.0 lbs/container

Cost = 12.0 x \$.48 = \$5.75

Summary

	Weight (lbs)	Cost
Extrusion	37.3	\$17.50
Rivets	2.7	2.20
Spacers	16.9	.72
Bottom Deck Board	20.4	2.23
Top Deck Board	18.2	2.15
Backup Plate	12.0	5.75
	107.5	\$30.55

Estimated Cost of Manufacturing Operations

	Time (min)
Mitre and notch four extrusions	10
Weld extrusion (4 corners, 6" long = 24" @ 2 in/min)	12
Drill and countersink 54 holes in extrusion	20
Form, notch, and drill backup plates	10
Assemble and head rivets	10
Drill plywood and spacers	20

Assemble bottom deck to extrusion	3
Total Direct Labor Time	85
Total Direct Labor Cost ($3.00/hr)	$4.30

Tooling Required

Extrusion die	$ 200
Notching	2,000
Drill fixtures, clamps, etc.	1,000
	$3,200

FABRICATED STEEL DESIGN - LOTS OF 5000

Steel Frame - 1/8" x 9" wide

Weight of purchased material = 57 lbs

Weight of steel removed from cutouts = 2.6 lbs

Actual weight of frame = 54.5 lbs/container

Cost @ $.15/lb = $8.55/container

Steel Corner Plates - 5-5/8" x 5-5/8" x 3/4"

4 required

Weight = 26.5 lbs/container

Cost = 26.5 x $.15 = $4.00/container

Rivets - 1/2" x 4-1/4"

40 required

Weight = 40 x .25 = 10 lbs/container

Cost = 10 x $.40 = $4.00

Wooden Spacers - Douglas Fir

7.25 bd ft required

Weight = $7.25/12 \times 28$ lbs/ft^3 = 16.9 lbs/container

Cost = $\$.10 \times 7.25 = \$.72$/container

Bottom Deck Board - 1/2" Plywood, Exterior Grade

20 ft^2 required

Weight = 20×1.5 lbs/ft^2 = 30 lbs/container

Cost = $20 \times \$.165 = \$3.30$/container

Top Deck Board - 3/8" Plywood, Exterior Grade

16.5 ft^2 required

Weight = 1.1 lbs/ft^2 $\times$ 16.5 = 18.2 lbs/container

Cost = $16.5 \times \$.13 = \$2.15$/container

Backup Plate - Aluminum 1/8" x 5"

196" required

Weight = $.625 \times 196 \times .1 = 12.0$ lbs/container

Cost = $12.0 \times \$.48 = \$5.75$

Summary

	Weight (lbs)	Cost
Steel Frame	54.5	$ 8.55
Steel Corner Plates	26.5	4.00
Steel Rivets	10.0	4.00
Wooden Spacers	16.9	.72
Bottom Deck	30.0	3.30
Top Deck	18.2	2.15
Backup Plate	12.0	5.85
	168.1	$28.47

Estimated Cost of Manufacturing Operations

	Time (min)
Blank 4 steel edge strips	2
Form 4 steel edge strips	10
Weld 18 bolt indentations	24
Cut and rout bottom deck board	6
Assemble and weld complete bottom deck	18
Drill and countersink 40 rivet holes in bottom deck	15
Drill rivet holes in wooden spacers and top deck board	15
Form, notch, and drill backup plates	10
Assemble and head rivets	10
Total Direct Labor Time	110
Total Direct Labor Cost	$5.50

Tooling Required

Blanking dies	$1,500
Forming dies	2,000
Drill fixtures, clamps, etc.	1,000
	$4,500

ALUMINUM EXTRUSION "CHANNEL" DESIGN - LOTS OF 5000

Extrusion - ALCOA Alloy #6062-T6

Weight = 1.80 lbs/ft

= 29.4 lbs/container

Cost = $.47/lb (30,000-lb quantity)

= $.47 x 29.4 = $13.80

Bottom Deck Board - 1/2" Plywood, Exterior Grade

Area = 15 ft^2

Weight = 1.5 lbs/ft^2 x 15 = 22.5 lbs/container

Cost = \$.165 x 15 = \$2.45

Top Deck Board - 3/8" Plywood, Exterior Grade

Area = 16.5 ft^2

Weight = 1.1 lbs/ft^2 x 16.5 = 18.2 lbs/container

Cost = \$.13 x 16.5 = \$2.15/container

Wooden Spacer (center)

3 bd ft required

Weight = 3/12 x 28 lbs/ft^3 = 7.0 lbs

Cost = \$.10 x 3 = \$.30

Summary

	Weight (lbs)	Cost
Extrusion	29.4	\$13.80
Bottom Deck	22.5	2.45
Top Deck	18.2	2.15
Wooden Spacer	7.0	.30
Adhesive	----	.25
	77.1	\$18.95

Estimated Cost of Manufacturing Operations

	Time (min)
Mitre, notch, and pierce four extrusions	12
Weld extrusions (4 corners, 8" long = 32" @ 2 in/min)	16
Assemble top deck, wooden spacer, and bottom deck to extrusion and bond	5
Total Direct Labor Time	33
Total Direct Labor Cost ($3.00/hr)	$1.65

Tooling Required

Extrusion die	$ 200
Notching die	2,000
Piercing die	500
Fixtures, etc.	500
	$3,200

APPENDIX VII

DETAILED COST ESTIMATE FOR CONTAINER STRUCTURAL FRAME AND DOOR FRAME

Material - 6062-T6 Alloy

Estimated in lots of 5000 containers

STRUCTURAL FRAMEWORK

Extruded section

Area = .187 x 2.75 = .51 in^2

Weight = .51 x 130 x .1 = 6.7 lbs

Cost = 6.7 x \$.48 = \$3.20

3/16" x 1" x 1" angle

Length = (2 x 65) + (2 x 44) + (2 x 54)

= 130 + 88 + 108 = 326 in

Weight = 326 x .375 x .1 = 12.2 lbs

Cost = 12.2 x \$.48 = \$5.85

3/16" x 1" strap

Length = (4 x 85) + (2 x 80)

= 340 + 160 = 500 in

Weight = 500 x .187 x .1 = 9.3 lbs

Cost = 9.3 x \$.48 = \$[illegible].50

Total material weight = 28.2 lbs

Total material cost = \$13.55

Manufacturing Operations

	Time (min)
Cut to length	10
Assemble in welding fixture	5
Weld (50 in)	25
	40

Labor cost (40 min @ \$3.00) = \$2.00

Overhead (150%) = 3.00

DOOR FRAME

Material - Extrusion

Area = .187 x 1.75 = .327 in^2

Weight = .327 x 130 = 4.25 lbs

Cost = 4.25 x \$.48 = \$2.05

3/16" x 1" strap

Area = .210 in^2

Weight = .187 x (88 + 160) = 4.65 lbs

Cost = 4.65 x \$.48 = \$2.25

Total material weight = 8.9 lbs

Total material cost = \$4.30

Manufacturing Operations

	Time (min)
Cut to length	3
Assemble in welding fixture	2
Weld (10 in)	5
	10

Labor cost (10 min @ $3.00)	=	$.50
Overhead (150%)	=	.75

Estimated Tooling Cost

Extrusion dies	$400
Jigs and fixtures	750
	$1150